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The Sino-Russian roulette of coal flows;
a multimodal optimization

by

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Abstract

The remarkable growth rates of the Chinese economy over the past decade have driven the world trade and have positioned the Asian country as the destination and origin of several international transportation routes. Bulk trade of iron ore and coal as major commodities has transformed into a sizable section of Chinese imports that fuels the domestic power and steel industries.

Since 2009, People's Republic of China has endeavored in importing coal from Australia and Indonesia. Production and consumption imbalances along with bottlenecks in the coal transportation system of the country are considered the main reasons that have made it more profitable for coal buyers to import coal than buy from domestic producers. Resource reservation policy and environmental reasons along with the 12th Five Year Plan of China hinder a preservation of the current importing status of the country. That has been the reason for various infrastructure developments in the neighboring Russia which aims to become the major coal exporter to China. Infrastructure developments have also been announced or are already under way in China in order to enable the domestic coal to reach at competitive rates to the final buyers. Therefore this thesis' research purpose is to estimate the future coal flows in the Chinese market, given the infrastructure developments of China and Russia.

In order to find suitable answers, a Linear Programming model has been developed with the purpose to estimate the optimal routes that would minimize the transportation costs of coal flows. Russia was estimated to be the most important coal exporter to China, should the infrastructure upgrades at its' network take place. Various scenarios were run at which the importance of Bohai Bay' s and Shandong's ports was underlined along with the increasing importance of Yangtze River in the coal transportation network of the China. Supply and demand swifts led to different results and highlighted the future role of Russia as the major provider of coal for the eastern coastal regions of China.

The findings demonstrated that the increased spending on infrastructure development in the Russian and Chinese coal transportation network will have a great impact on the trade dynamics of the regional market. It is stressed though that several factors should be taken into consideration when estimating future trade flows and not just cost and capacity criteria. Nevertheless, the model constructed could be a good indicator of the impact of infrastructure developments and could have applications on estimating specific infrastructure developments' impact on trade flows and as a consequence on a socioeconomic sphere.

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List of Abbreviations

AIMMS	Advanced Integrated Multidimensional Modeling Software
CESY	Chinese Energy Statistical Yearbook
CPC	Communist Party of China
COP	Conference of the Parties to the United Nations Framework
EIA	United States Energy Information Agency
FYP	Chinese Five Year Plan
IMF	International Monetary Fund
Da-Qin Line	Datong to Qinhuangdao railway line
Feng-Sa-Da Line	Fengtai to Dato railway line
Han-Chang Line	Handan to Changzhibei railway line
Hou-Yue Line	Houma to Yueshan railway line
Jing-Yuan Line	Beijing to Tongliao railway line
Ji-Tong Line	Jininan to Tongliao railway line
PRC	People's Republic of China
Shi-Tai Line	Shijiazhuang to Taiyuan railway line
Shuo-Huang Line	Shenchinan to Huanghua railway line
SOE	State Owned Enterprise
Tai-Jiao Line	Xiuwen to Jiaozubei railway line
TVE	Township and Village Enterprise
Xi-Kang Line	Xian to Ankang railway line
Xi-Nang Line	Xian to Nanjing railway line
Xi-Zheng Line	Xian to Zhengzhou railway line

Chapter 1: Introduction

“China is the world’s most populous country with a fast-growing economy that has led it to be the largest energy consumer and producer in the world. Rapidly increasing demand has made China extremely influential in global energy markets.”

U.S. Energy Information Agency

People’s Republic of China’s (PRC) primary source of energy is coal (70%) with oil accounting for almost 18% in 2013. Despite the country’s will to diversify its’ energy portfolio, alternative energy sources only account for the remaining 12% with hydroelectric capturing a leading 6 % (CESY). The 12th Five Year Plan of the country aims to reduce coal use to 65% by 2020 and according to U.S. Energy Information Agency’s (E.I.A.) estimations it will reach 55% by 2040. Despite the estimated reduction of coal use in the energy mix of the country, absolute coal consumption will increase by an astonishing 50% according to forecasts by E.I.A. that take into account the increase in total energy consumption. However the current supply and demand imbalances, the turbulences of demand in combination with the bottlenecks that are created at the main railway system of coal transportation and the restricted capacity of local non-dedicated lines make the need for infrastructure investments more important than ever. In the spirit of the 12th Five Year Plan, China will seek to import coal when prices are favorable, increasing the competition between its’ main foreign and domestic suppliers.

Given China’s ability to cover its’ consumption only by domestic production until recently, the country’s Energy policy is mainly determined by two factors. Firstly the new status that wants the country’s fast economic growth (7.7% GDP growth in 2012 according to IMF) to depend on foreign energy supply and secondly the subtle relation of energy and national security (Christie et al., 2010). According to Cao and Bluth (2013) China’s increasing reliance on imported energy has a clear strategic impact as it promotes a firmer integration with international financial and energy markets and also presents geopolitical challenges affecting the country’s relationship with Russia, Europe, U.S.A. and neighboring countries. After the latest political developments in 2013 that put Xi Jinping in the wheel of the country, the new administration has set energy efficiency and renewable energy projects as high priorities underlining their already stressed importance at the country’s 12th Five Year Plan of 2010. Policies to promote energy transmission infrastructure in order to improve links between supply and demand are in the Party’s agenda according to late 2013 official announcements.

China is the world’s largest producer and consumer of coal, accounting for more than 46% of global consumption according to International Energy Agency’s (IEA) estimates. It consumed almost 1.91 billion metric tons oil equivalent of coal surpassing by far the United States of America, the second in the list. However in 2009, it imported an astonishing 126 million tons and became the center of attention for the international coal trade.

At this point it is important to also underline that PRC has come a long way in terms of market structure and importance after its' foundation in 1949. Starting off as a centrally administered economy, bearing strong resemblance to the ex-soviet style, the Chinese market has evolved through a mixture of central planning and market oriented policies. After the Korean war of 1950, specific emphasis was given to the development of national interest industries and sectors, including the coal sector.(Peng 2011).

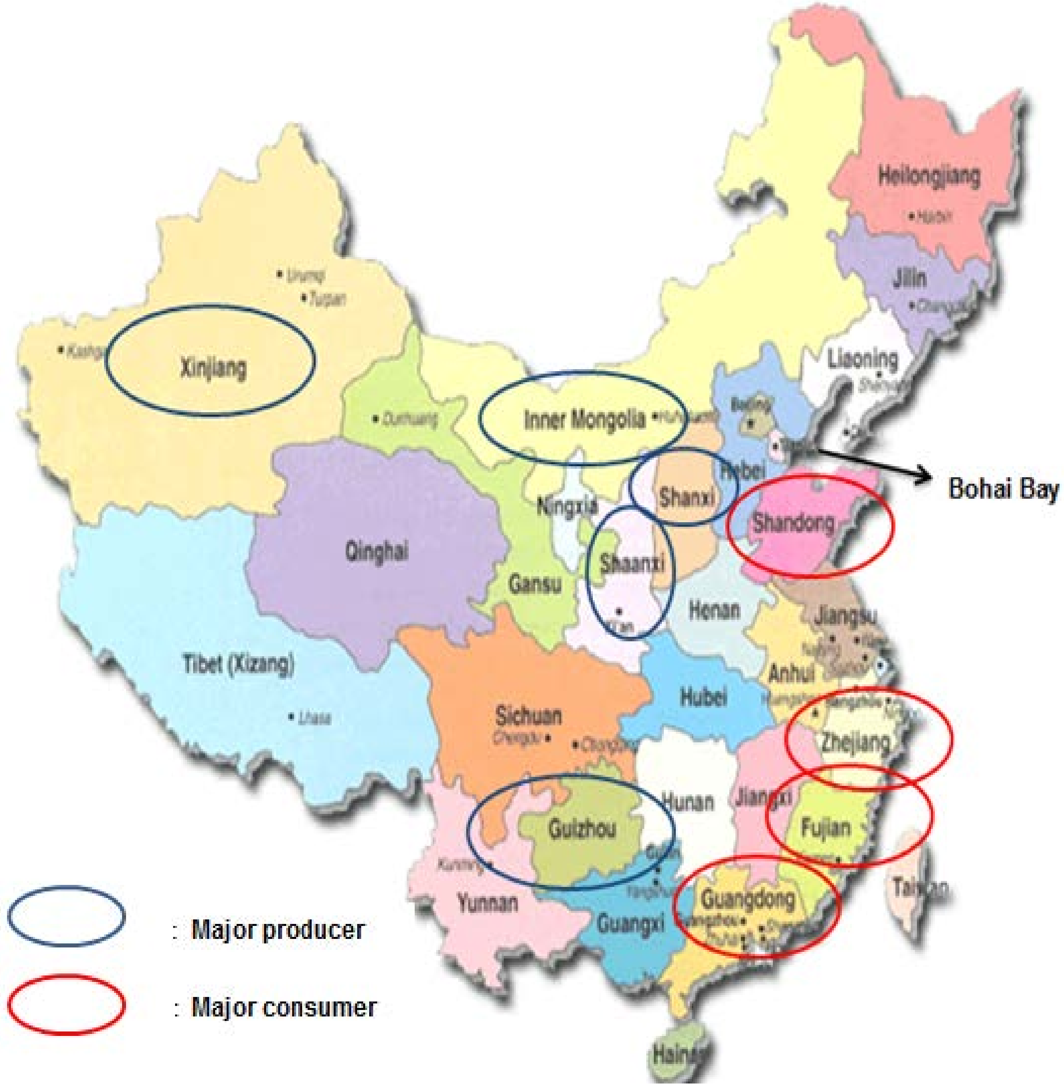
The reasoning behind the spike in imports is mainly the price difference of domestic with imported coal due to increased transportation costs. As Morse and Gang (2010) accurately express it in their research on China's coal import behavior, this situation can be characterized as "The world's greatest coal arbitrage". The market-oriented coal consumers considered it more profitable to import coal mainly from Australia and Indonesia to Guangzhou rather than to transfer it from the country's north-western producing areas.

Coal's main cost driver (according to EIA) is transportation cost and due to bottlenecks in the existing railway network of China, the transport costs for domestic coal led to relatively high prices at the consumption areas. Due to China's lack of southbound railway lines that could be used for coal transportation, the northwestern production is moved towards the northeastern ports of Bohai Bay and mainly Qinhuangdao and from there it is shipped towards Guangzhou and the neighboring coal consuming provinces of southern China.

1.1 Problem Identification

The contradictive situation described above is the outcome of the imbalances of coal production and consumption in the provinces of China in combination with transportation bottlenecks in the country's network. The production of coal is mainly concentrated to Northern and Western provinces and mainly Shanxi, Shaanxi, Inner Mongolia, Guizhou and Xinjiang provinces while the east and south east part of China including Guangdong, Fujian, Shandong and Zhejiang face major lack of coal (Figure 1). The producers of coal, using mainly the Daqin railway line, short-sea shipping from the Bohai sea coal ports, but also trucks, have been trying to cover the geographically imbalanced demand of coal. Bottlenecks in the railway system of China in combination with increasing prices of fuel that make the usage of trucks prohibitive have made it profitable to import coal from Australia, Indonesia, Russia and other countries.

Figure 1: Map of China with indicated major coal production and consumption provinces



1.2 Research Question

In accordance to the stated problem and the on-going infrastructure developments in Russia and China, this study will endeavor in providing an answer for the following research question:

"How the infrastructure capacity upgrades of Russia and China will affect the trade flows of coal towards the market of PRC?"

To shortly describe the research question, we should look closely at the implied elements of it. It firstly takes into consideration the infrastructure developments in the port and rail sector both in Russia and China. These developments are identified as capacity upgrades in the transportation system of the two countries that will enable the movement of larger quantities of coal. Second the coal flows basically represent the movements of coal with various means of transportation. Therefore, on one hand it is acknowledged that we are dealing with a transportation problem and on the other hand it is acknowledged that this transportation problem involves different modes and is in fact a multimodal transportation problem.

In the effort of providing an answer to the main research question, based on logical steps the following sub-questions will need to be answered first:

1) "In what way will the inland waterways of Yangtze river in combination with increased port capacity and new railway infrastructure affect the inter-regional coal flow of China?"

2) "How will the Russian coal export flows to China be affected by the increased capacity of their transportation infrastructure in comparison with the major suppliers of coal to the Chinese market?"

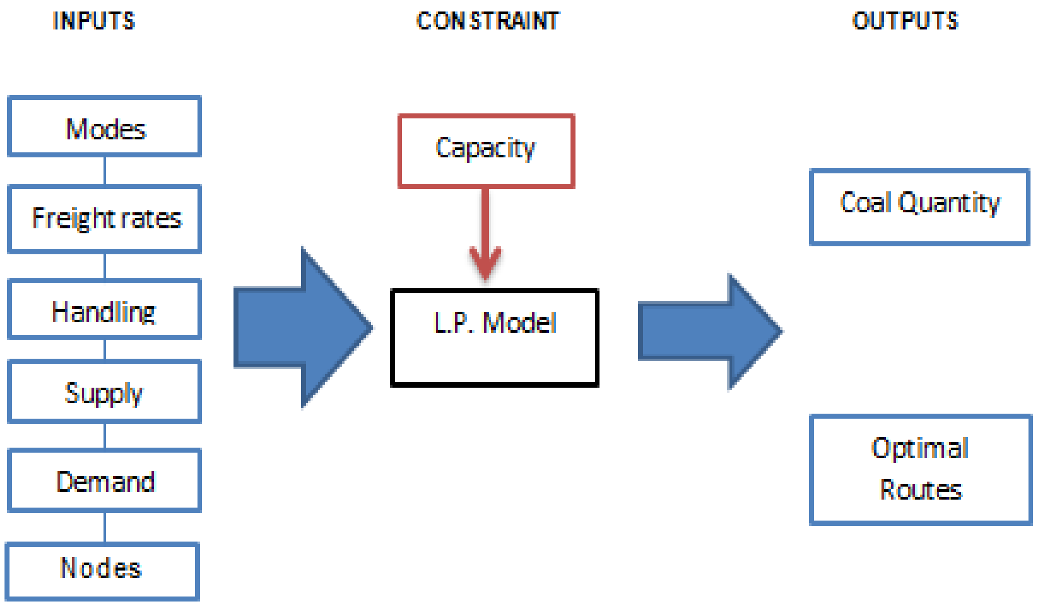
3) "In what way will transportation and handling cost variables affect the route decisions of coal exporters and domestic importers?"

4) "How would a potential shift in the coal supply centers of China affect the optimality of transportation patterns?"

The four sub-questions can be categorized into three different categories, based on the main parameter that will be examined. The first two are mainly involved with the capacity constraints in the system while the third examines the cost parameter's effect on transportation patterns and the fourth sub-question is about demand and supply changes' effect on the optimal routes.

Therefore in order to answer those questions a Linear Programming model is chosen as the most appropriate method. The Linear Programming model that will be developed will involve the cost parameter which will be affected by distances. Freight rates and handling costs will also be taken into account along with demand and supply at each separate province. Capacity will be set as a constraint with appropriate values on each route taken. A schematic representation of the inputs and outputs of the model applied is given at Figure 2 below while a more detailed description of the model will be presented at chapter 4.

Figure 2: Schematic Representation of the Inputs and Outputs of the model



Prior to the constructed model's application, certain subjects need to be introduced to the reader as they play a significant role in comprehending the methodological approach and certain practical aspects of this research.

Figure 2 gives a clear overview of the line of thinking that will lead to the answer of the suggested sub-questions and main research question. Thus, Chapter 2 will involve an introduction to the reasons of the increase in Chinese coal imports, as those are addressed in the literature. Additionally, the challenges in the transportation network of coal trade in China will be presented along with a closer look at multimodality and research on that specific scientific field. The methodological approaches of various researchers will finally be presented parallel to the methodological approach of this thesis.

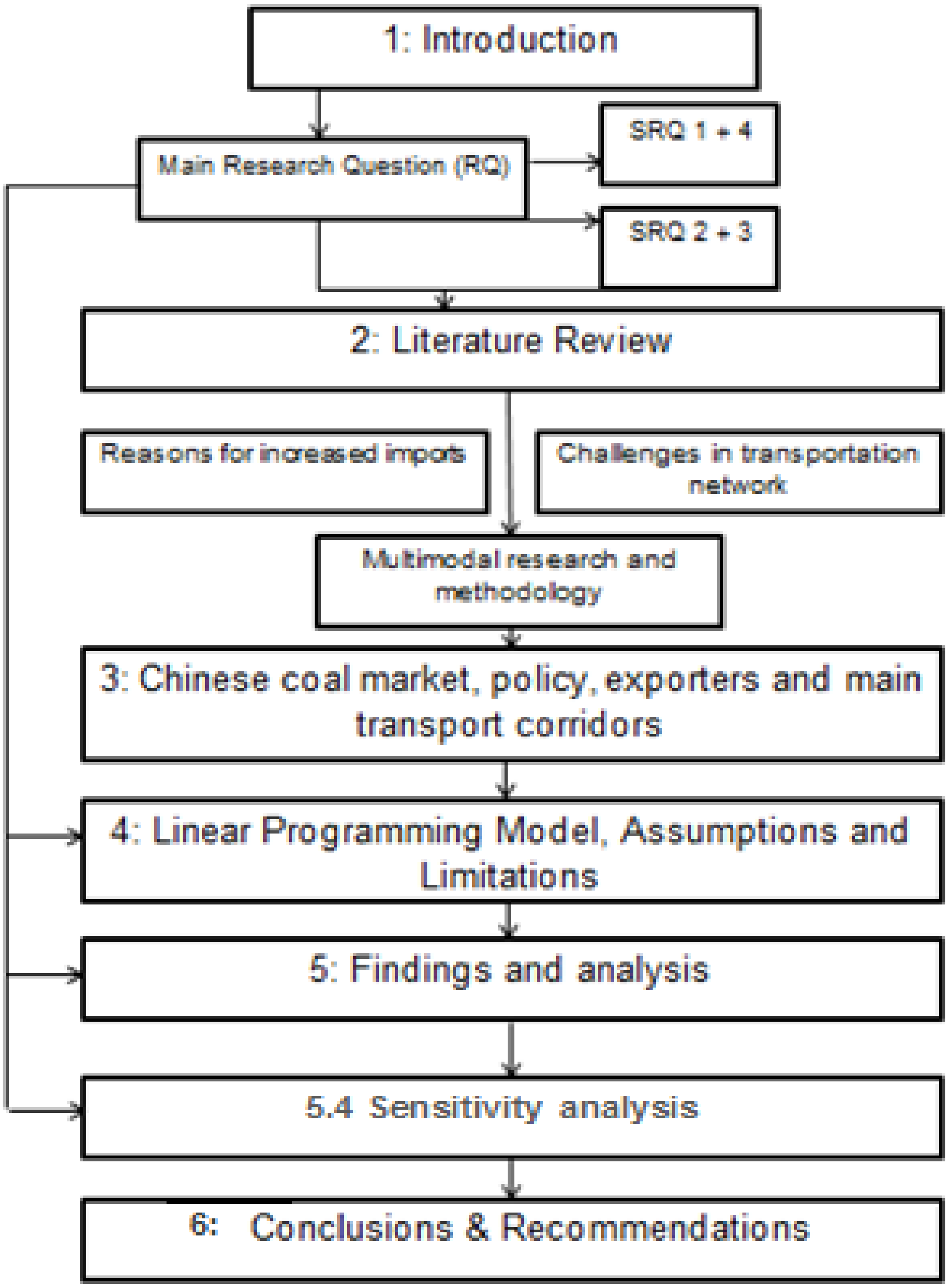
Chapter 3 will provide an overview of the Chinese coal market and coal policy. That will involve a closer look at the 12th Five Year Plan of China, the supply and demand imbalances, the coal types mainly imported to China and the domestic coal industry's structure. Most importantly the main transport corridors, the main trade partners and the major infrastructure developments will be presented at this section of the research.

Chapter 4 will involve the explanation of the fundamentals of the methodological approach. A description of the constructed Linear Programming model typically contains the mathematical explanation and the introduction to AIMMS, the software that will be used to solve the objective function. The assumptions taken during the model formulation and application will also be presented at this chapter along with the limitations of it.

Chapter 5 will present the findings and analysis of the L.P. model three basic scenarios' solutions. Those scenarios are firstly a representation of the current situation of the coal flows and secondly an assumption of transportation system where capacity infrastructure is adequate to cope with the demand. Third, a scenario which will involve supply center and demand changes will be applied in an effort to estimate future trade flows. At the chapter's final part, the findings of a sensitivity analysis which involves the applications of two different scenarios will be presented.

At chapter 6 the final conclusions will be presented along with recommendations for policy and business decisions. Those recommendations will be based on the results and analysis of the scenarios at the previous chapter. The main question to be answered will be whether an investment in an upgrade of the capacity of the Russian Pacific ports and railways will provide the Russian coal exports with a competitive advantage on the Chinese market, given also the infrastructure upgrades in China. At the last part of the chapter, recommendations for further research will be provided as well as proposals for different applications of the L.P. model created.

Figure 3: Overview of the thesis' structure



Chapter 2: Reasons for increased coal demand, challenges in transport network and multimodality

This chapter gives an overview of the researches on the coal transportation in China along with the researches in the literature on multimodal transportation. It provides the theoretical foundation for this research and acts as a starting point for the next chapters. At section 2.1, a reference to the research in the literature on the increase in the Chinese coal imports is made. In addition, a closer look at the transportation challenges that are acknowledged by other researchers is given in section 2.2. Finally the methodological approaches on multimodal transportation problems are identified at section 2.3 along with an introduction at the methodological approach of this research and its' added value comparing to the previous.

2.1 Reasons for the increase in Chinese coal imports addressed in the literature

A series of researches on the coal import-export of China have underlined all the factors that led to the increase in coal imports. Those factors can be categorized based on the main research field of the available studies and are: a) Logistics bottlenecks b) Environmental c) Policy related and d) Resource preservation related.

<u>Logistics bottlenecks</u>

The port sector of PRC has managed to keep up with the capacity requirements of the increasing demand and therefore ports are not considered to be major bottlenecks even though there are certain regulatory and administrative obstacles that hinder their performance (Zhang & Figliozzi 2010). The capacity constraints on Ji-Tong, Shuo-Huang and especially Da-Qin lines that serve the north route along with the increased fuel costs, as truck usage is unavoidable, have been the main reason behind the increase in prices of domestic coal. Mainly due to administrative issues (Tu & Johnson-Reiser, 2012) the railway capacity has not followed the increase in port capacity.

<u>Environmental reasons</u>

Paulus et al. (2011) have examined the hypothesis that the trade patterns of the steam coal market follow a non-competitive market behavior by developing an equilibrium model between China and Indonesia in an attempt to identify the coal producing nations as strategic players. As a strategic player in the coal market, China was also the number one carbon emitter by 2007. Therefore, China has adopted a more relaxed import policy in accordance to it proposal of 2009 to reduce carbon intensity by 40-45% by 2020 (Tu & Johnson-Reiser 2012).

Research on reducing the country's reliance on coal and its intensity on energy have been conducted by Li, Sun, Feng and Zhu (2013) who used the DEA-Malmquist approach to examine the different effects of technological changes in regions. Those kinds of researches are representative of the trend that wants more efficient and environmental friendly technologies to be implemented in coal production and transportation. In the same spirit, Zhenguo (2011) has conducted field surveys and analyses on the sustainable development practices regarding the work force, power and methods used in the process of coal production.

Before the "2009 turn to the markets" of the Chinese coal buyers, several problems of the country's mining industry had been addressed by researchers outside China as well. The World Bank Energy Sector Management Assistance Program (ESMAP, 2008) and the International Energy Agency (IEA, 2007) had addressed issues on sustainability and energy efficiency respectively. Other researchers on the field had looked into the country's strategic decisions as a means to improve its energy efficiency (Sinton et al., 2005; Zhou Nan et al., 2007). On the other hand, research that has been done in the CO2 reduction of China has indicated that the growth rate of the Chinese economy will lead to massive emission levels by 2030 that cannot just be offset by any efficiency gains (Guan et al. 2008). Pollution in general and carbon efficiency in particular have put the People's Republic of China in the spotlight during the United Nations Framework Convention on Climate change COP17, making the central government rather worried of its' carbon footprint.

Policy-related reasons

One can easily derive from the 12^{th} Five Year Plan of the People's Republic of China that the reform of the domestic coal industry is among the main goals of the Government.(12^{th} FYP). Besides the ecological aspect, safety is another important issue that worries the policy makers. Small, privately held coal mines that attribute to a relatively high fatality rate (56.4 deaths per 100 million metric tons in 2011 according to the State Administration of Work Safety) can be consolidated or shut down as the imbalance of coal demand is facilitated by imported coal. According to Tim Wright, professor at University of Sheffield specializing in coal mining, among the factors that have led to the steep decrease of fatality rate (37 deaths per 100 million metric tons in 2012) in Chinese coal mines is the increase in competition and the shutdown of smaller mines.

The tight regulation of China on domestic prices of coal based energy providers along with binding long term contracts with domestic coal mines have led to a situation under which the Chinese coal providers cannot cope with the demand and find no incentive in fulfilling larger orders due to the low rates that their product is being sold. Imported coal is a short-term solution to that problem, until a consolidation of the market takes place(Tu & Johnson-Reiser 2012).

Resource preservation

Another aspect of the Chinese coal market that promotes the increase of imports in coal is the scarceness of coking coal in comparison to steam coal reserves. International Energy Agency's definition of coking coal states that it is the coal with the quality that allows the production of coke and has a calorific value greater than 5700kcal/kg. Coke is used in steel production and due to Chinese steel industry's increase rate the Chinese Government has started importing coking coal since 2004 as a means to protect its depleting reserves. It is interesting to underline at this point that China is the leading importer of coking coal accounting for almost 20% of global coal trade (I.E.A).

2.2 Challenges in transportation addressed in the literature

Since the main focus of this thesis will be on the transportation challenge of the coal trade flows a more detailed approach on the researches that address that issue in the literature is considered vital to give the reader a better grasp of the subject.

Bottlenecks

With Da-Qin being the main dedicated coal railway line in the northern part of China and not being able to cope with the increasing demand, one can easily assume that the railway transportation bottleneck is one the major reasons and drivers behind the major increase in imports of coal. Being one of the pillars of the 12th Five Year Plan of the Government, the transformation of freight railways in China has been the center of attention for the researches of several academics that on one hand doubt the feasibility of creating sufficient track capacity(Pittman 2011) and on the other hand underline the importance of railway expansion and policy change (Huaichuan et al., 2010). It is interesting to note that two decades ago academics had proposed multimodal patterns of transportation in order to achieve efficient coal transportation chains (Miles 1981).

Miscommunication

In the field of research on the reasoning behind the new trade patterns in the Pacific coal trade towards China, Zhang and Figliozzi (2010) underline among others the lack of an integrated transport network at a national level mainly due to poor communication between the different ministries that regulate each mode.

2.3 Multimodal Research

The main problem addressed lies in the framework of multimodality as several modes of transportation are combined in order to provide the most efficient routes for coal movements in terms of time and especially cost. Literature on multimodal research is quite extensive despite the fact that it is an emerging research field.

2.3.1 Definition of Multimodality

As Bontekoning et al. (2004) have so accurately expressed, intermodal freight transportation research can be identified as an emerging research application field in its’ first stages of development. In the process of defining multimodal transportation several definitions can be found in the literature review, ranging from general to very specific (Bontekoning et al. 2004). Crainic (2007) has defined multimodal transportation as the transportation of a person or load by combining at least two modes and the transfer of one mode to another, taking place at an intermodal terminal. Despite the previous being quite general one even more general definition that according to the author is closer to the perception of multimodal transportation of the present thesis is provided by Min(1991) who defined multimodal transportation as the movement of cargo from origin to destination using a combination of different modes such as air, ocean carriers, barges, rails and trucks.

2.3.2 Methodology

In the field of multimodal research in Europe and in the United States, Zografos and Regan (2004) and Vrenken (2005) have examined the challenges that large-scale intermodal transportation systems face. The optimal combination of different modes of transportation along with improvements in the capacity of railways and ports according to Mou & Li (2012) can be the solution towards the energy sufficiency of China.

The modeling problems that need to be assessed along with a general overview of the opportunities on the field of operations research in multimodal transportation were the research objective of Macharis and Bontekoning (2004), while an update on the challenges and opportunities presented in the field has also been provided by Macharis in cooperation with Caris, and Janssens (2008). One could categorize the research done on the field of multimodal transportation based on the emphasis given to each mode and the decision makers involved(Caris et al. 2008). From the network operators' part significant research has been done on the redistribution of railcars, barges and load units (Chih and van Dyke, 1987) and on positioning of terminals (Kapros et al., 2005). Barnhart and Ratiff (1993) analyzed methods to optimize cost in intermodal routes along the whole transportation chain by categorizing decision sets in two types. Boardman et al. (1997) created a decision support system that would lead to lower transportation costs by combining truck, rail, air and barges while Erena et al. (2005) focused on optimal routing of loaded tank containers and repositioning of empties and concluded that repositioning decisions are better to be done on a daily basis. Min(1991) added service effectiveness to the cost efficiency by constructing a Goal Programming model that would allow the user to combine different modes efficiently by taking under consideration among others costs, distance, speed, risk, capacity and market coverage. Chang(2007) proposed an heuristic algorithm in order to solve the proposed multiobjective multimodal multicommodity flow problem (MMMFP) that would indicated the best routes in international intermodal networks.

Various scientific approaches have employed descriptive and quantifying methods in the emerging field of intermodal transportation research. Sirikijpanichkul et al. (2007) have analyzed the agent based modeling approach in order to identify the optimal locations of intermodal freight hubs while Satar et al. (2009) estimated a generalized shipper transportation cost function to test the allocative efficiency of coal shippers. The over-use of trucks was identified as a finding due to price distortions in the market of transportation. Chang and Sinha (1980) developed a two-stage model general model that accounts for different modes and assigns flows according to efficiency criteria as a method to determine optimal, multimodal coal-shipping patterns. China's coal transportation has also been studied quantitatively by Mou and Li (2012) in the aftermath of the country's "turn to the markets". A linear programming model that accounted for volumes and directions of coal flows was developed in order to analyze the optimal transportation patterns for domestic coal flows taking under account future shifts in production and capacity constraint of the Daqin railway line. Despite the clear scientific and market interest of Mou and Li's research, the fact that they did not take under account the competition from neighboring coal producing nations on one hand underlines the importance of China's self-sufficiency on energy but on the other hand is a bit away from market reality and not in consistence with the Government's Policy as this can be implied by international trade agreements and the 12th five year plan of 2011.

The methodology of this thesis

Similar to Mou and Li's (2012) research the author will also take into consideration the existing and future (expected) capacity constraints. A linear programming model to minimize the total transportation cost of the whole transportation chain of coal, similar to Chang and Sinha's (1980) will be developed to take into consideration supply from Indonesia, Australia and especially Russia which has developed into a major coal provider for the Pacific region (IEA). Infrastructure developments will also be incorporated into the model (e.g. the Three Gorges Project, the construction of new railway lines in China, in Russia and across the Sino-Russian borders such as the Mizhneyeleningkoye-Tunjian line and the reopened Hunchu-Makhalino line). In that way a clearer view of the future trade flows could be demonstrated in a way that will be consistent with the existing market conditions. Also projected demand and supply imbalances will be taken into account in an attempt to establish different optimal routes under different criteria related to the PRC Government's trade and energy policies. AIMMS software will be applied to solve the optimization equation proposed. AIMMS is a development environment that allows its' user to develop optimization-based applications (Bisschop, 2004). Adding to previous researches on the field of multimodal transportation the main contribution of the model applied in the present thesis will be the usage of a Linear Programming optimization model in order to identify trade flows, taking under account constraints on capacity as well as external competition. The model that will be created will have applications on the estimation of various projects that have to do with capacity expansions, but can also be used to estimate the impact of policy changes that result to demand or supply alterations.

Major Findings

SRQ 1 – 4:

- A thorough research was conducted on the literature related to the subject of the present thesis. That way an understanding of the research background was developed which allowed the identification of the factors behind the increased coal demand of China and of the challenges in its transportation network.

- Main factors for increased imports
    - Logistics bottlenecks
    - Environmental related
    - Policy related
    - Resource preservation related

- Main challenges in transportation
    - Bottlenecks
    - Miscommunication

- The methodological approach of related studies was described along with the approach of the current research. Existing and future capacity constraints will be taken into consideration and a Linear Programming model will be developed that will be solved by using AIMMS. In addition to existing studies, the methodology applied in this thesis will also take into account the external competition.

Chapter 3: China's coal market

At chapter 3, an analysis of the Chinese coal market, its' policy, structure, transportation corridors and bottleneck is provided in order to assess the significance of coal as an energy source for China and also a market opportunity for the major coal exporters. A description of the three top coal exporters is also provided along with the infrastructure developments in Russia and China. That will enable us to access the future supply and transportation capacity of the two neighboring countries but also any future possible course of demand or supply alterations in the Chinese market.

3.1 China's Energy fueled by coal

According to the National Bureau of Statistics of China, thermal power has been the major component of electricity generation the past 20 years. Its' major component, coal, has fueled an increase in the general energy demand of China that is attributed to the high rates of economic growth that the country has achieved since its' opening up to the markets.

Primary Energy consumption

Coal has accounted for most of China's energy consumption in 2011, 2012 and 2013, accounting for almost 70% with the Energy International Administration predicting a fall to 63% by 2020 and 55% by 2040. Nevertheless the absolute numbers of coal quantities will keep growing along with the Chinese population and economy increases.

Energy efficiency

Energy efficiency practices in the thermal power sector along with the inclusion of natural gas in the classification of thermal power by the Chinese statistics agencies, are the main reasons for the differences that have been noted during the past 5 years between the growth rate of thermal power and coal consumption in the sector. According to Tu and Reiser (2012) if it were not for the energy efficiency being a top priority for the sector, a mere 543 million tons of coal would have been wasted in 2009. From an environmental perspective, according to a research conducted by Peters and Hertwich (2008), the emissions of CO_2 due to energy inefficiencies embodied in the Chinese exports were four times higher than those in imports. This argument supports the Chinese government's will to consolidate the power sector and focus on energy conservation.

Steel Industry’s Energy efficiency accomplishment

The growth of the Chinese Steel and iron industry should be considered in the current stage of this research as it has been the main driving force for coking coal demand spikes during the past five years. Despite the country’s resource reservation policy and the industry’s significant energy gains, the growth of the Chinese Steel and Iron industry remains the major factor on determining the future of coking coal imports in the country. The usage of recycled steel, the increase of domestic producers of coal and the building of state-of-the-art mills are the main factors that indicate the large energy efficiency improvements of the sector.

Advanced Coal technology in China

The emergence of advanced coal technologies during the past ten years in China is significant and indicative of the resilience of coal as a major component of the country’s energy consumption structure. Despite the high-efficiency mining technologies that have been prioritized by the Ministry of Science and Technology of the country, other technologies include: Integrated Gasification Combined Cycle systems, Ultra Super Critical and Pulverized Coal facilities, Supercritical Circulating Fluidized Bed technologies and coal liquefaction and gasification technologies (Zhao & Gallagher 2007).

The diversified end use of coal however has certain negative effects as well. For instance certain technologies have inefficient requirement that make their usage not as efficient as one would think (CTL has massive water requirements). Air quality is deteriorated due to the increased coal related emissions; despite the fact that coal usage diversification aligns with the central policy, the impact on the environment brings out certain contradictive results.

3.2 Types of Coal –Two different markets

Coal is a substance quite complex that varies in consistency, quality, appearance and of course usage. The distinguishing factors between the different types of coal are the chemical and physical qualities of it. The energy content and water content are those that define its purpose usage and lead to not so clear distinction, depending on every country’s perception, between two main different categories of coal; Hard coal and Brown coal (lignite).

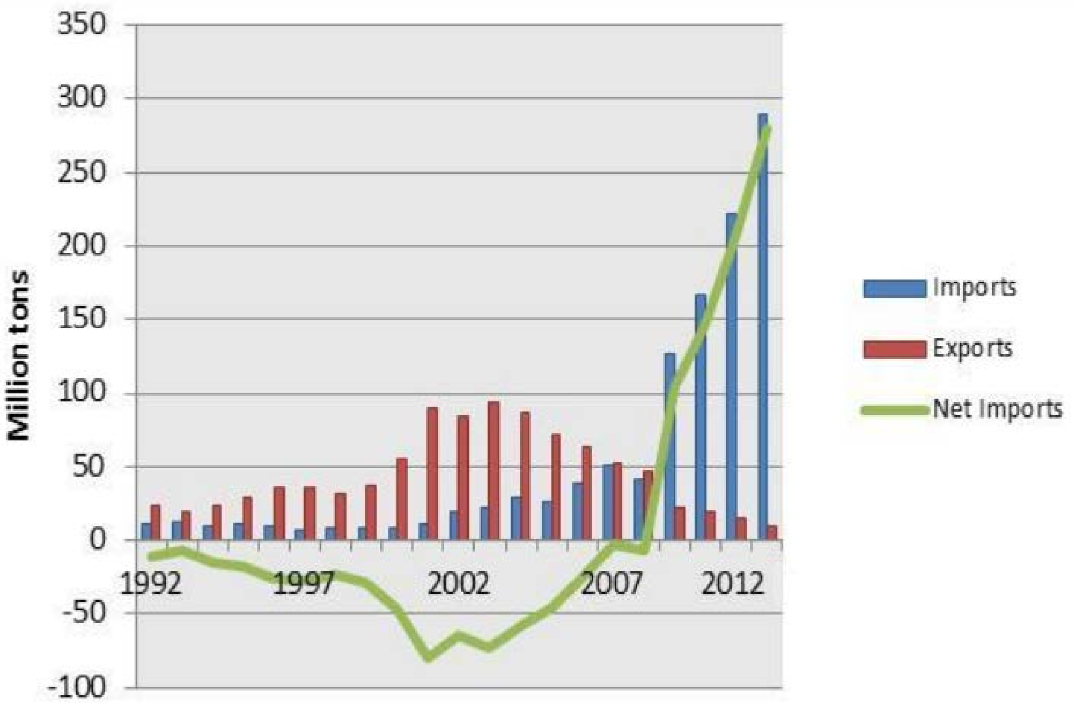
Hard coal has energy content higher than 4.500 kcal/kg and is traded globally while lignite has an energy content of less than 4.500 kcal/kg and is only traded locally. The scope of this thesis will focus only on hard coal and its' main two subcategories: Steam coal and coking coal. The first is used for power generation and industries while the second is used to make coke by the iron and steel industry. (Cornot-gandolphe 2013)

According to Tu and Reiser (2012) the definition of coking coal in China is a bit different than from many western countries' classifications and involves a broader range of coals following the Soviet standards. Due to the broad distinction of coking coal there is a danger of mismatch between the statistics provided by European and American agencies and those provided by Chinese. That will be taken into consideration during the formulation of the applied model and the adjustment of the available data.

3.3 China became the largest coal importer in 2011, overtaking Japan

China overtook Japan in 2011 as the world's largest importer. Despite the fact that its' coal imports for 2012 accounted for 23% of the international trade, they only accounted for roughly 7% of the domestic coal trade(Cornot-Gandolphe 2013). From 2 million tons in 2000 and 41 million tons in 2008, 182 million tons were imported in 2011, 289 million tons were imported in 2012 (Figure 4) and 134 million tons for 2014's first five months denoting the continuous rise in Chinese demand for coal (EIA). However this situation can only be sustainable as long as the factors that have given rise to it continue to exist. According to the 12th Five Year Plan of PRC, reliance on the country's own sources is one of the energy policy targets along with diversification of the energy mix towards more environmentally friendly fuels. Despite the contradictive nature of those targets, the significant capacity extensions on the coal transportation system of the country, along with the closing of small mines and focus on large scale investments, lead to the conclusion that intention of the Chinese authorities is to achieve a status of self-sustainable coal production that is away from the residential areas and import coal only when the markets allow it. Therefore the future on Chinese coal demand for imports lays on two criteria: a) Efficiency of the domestic transportation network b) international market prices – as affected by fuel prices, freight rates, quality of coal, expectations on availability. Nevertheless, even if China manages to achieve self-sufficiency of coal, the tonnage of coal that will continue to be imported in order to cover seasonal needs that fulfill the aforementioned price arbitrage criteria will be considerable.

Figure 4: Chinese coal imports and exports since 1992



Source: IEA, 2011 and 2012: China Customs data, Cornot-Gandolphe (2013)

3.4 Structure of Demand and Usage of coal

Usage of coal according to data provided by the Chinese Statistical Yearbook for 2012, thermal power was the main user of coal accounting for almost 62% with coke production coming second at almost 10% of the total coal usage.

Thermal power has been the main consumer of coal and the driving force behind the increased imports and productivity of the last decade in PRC. The steel industry that uses coking coal to transform it into coke which is a major component of their products comes second in the demand for coal accounting for almost 10% of the total demand for the last 9 years.

3.5 Coal Industry Structure

The coal industry of China can be divided in three subcategories according to Tu and Reiser (2012), depending on the type of enterprises that exist in the market:

a) First are the large State Owned Enterprises that are controlled by the central government on strategic levels and the provincial governments on a more administrative basis.

b) The second are the local State Owned Enterprises that are controlled and owned by the local government but have marked a decline in their market share and in 2009 accounted for roughly 12% of the national coal output (Tu & Johnson-Reiser 2012).

c) Third are the many Township and Village Enterprises that are owned by agricultural collective economic organizations and peasants. In 1991, their number exceeded 100,000 but through coordinated consolidation efforts of the central Government it has gradually reduced. However they account for a large share of national production of coal that approaches 40%.

3.5.1 Characteristics

The consolidation and the restructuring of the coal industry as it was dictated by the 12th FYP has a strong logical basis if one considers the differences between the major two types of coal enterprises (Table 1).

As far as the merger of numerous State Owned Enterprises (SOEs) is concerned, the creation of larger enterprises that is the outcome will eventually lead to a more efficient productivity. The costs will decrease due to economies of scale, the market share will increase and since the know-how and standards of different companies will be combined, a better productivity rate is expected. Apart from that, the creation of large coal enterprises that are owned and controlled by the central government, justifies the development of transportation infrastructure to accommodate their output.

On the other hand, the consolidation and closure of many small Township and Village Enterprises (TVEs) is a much anticipated move from the CCP if one considers their negative impact to the society, economy and environment. Due to their low safety and environmental standards that are results of lack of training, education and control by the central government, the numerous TVEs do in general more harm than good to the Chinese coal market. The high death rate amongst their employees adding to the tax evasion, the underreporting of production and the pollution of the environment have logically led the central government to the decision to gradually close down all small mines.

Table 1: General Characteristics of SOEs and TVEs

SOEs	**TVEs**
High production costs	Low production cost and quality
Larger market share	Decreasing market share
Low death rate	High death rate
Technological and environmental standards	Tax evasion, low environmental standards, underreporting of output
Large number of workforce	Unspecialized, ill-trained staff
Better connectivity to transportation corridors	Flexibility

Source: Sxcoal, CCII, Thomson (2003), Tu & Johnson-Reiser (2012)

3.6 Province categorization based on coal production and consumption

In order to better assess the future demand levels and consumption patterns of coal in People's Republic of China (domestic and foreign imports), one has to look firstly the country at a provincial level. The Government's intention to increase energy efficiency, reduce emissions, reduce coal usage and production and also increase dependence on alternative fuel (12th Five Year Plan, 2010) will be weighed against the current status and dependence of each province on coal.

<u>Anhui; a self-sustainable province</u>

According to Tu and Reiser (2012) Anhui province had a 10% yearly growth on consumption and production of coal until 2012. It satisfies major part of the demand of the eastern coast and a large portion of its' own production is used to satisfy the demand of the coal-fired power plants that are situated within the province. To achieve a more efficient transportation method the "Anhui Electricity to the East" program (ChinaPower, 2012) involves the dispatchment of electricity produced in Anhui through a major power grid and presupposes the increase in the province's electricity generation capability. Given the fact that almost 50% of the plants built after 2005 are coal fired along with the increased presence of cement, steel and chemical plants in the province and the low hydropower potential of Anhui, coal demand in Anhui and its' neighboring provinces is likely to increase in the next years with an 8-9% rate (ChinaEnergyGas.com, 2012)

Inner Mongolia; a producing province

The major and smaller coal deposits of Inner Mongolia include Shengfu-Dongsheng , Shengli, Zhunge' er coal fields and account for 31% of China's coal market (CESY, 2012).The production capability of Inner Mongolia is driven by the increase in demand of the Yangtze Delta and southern-coastal provinces of China. Coal produced in the province is exported via two major railway lines, that are owned by the Shenhua Group and have a total capacity of 230 million tons and the pre-existing Da-Qin line that connects Datong with Qinhuangdao Port, adding another 400 million tons to the total exporting capacity of Inner Mongolia.

As it was underlined in the 12th FYP overview at a previous part of the research, the CCP intends to transform Inner Mongolia and Xinjiang into the two major coal providers of China's increased coastal demand.

The two provinces examined above are characteristic and representative of most of the provinces of China. Based on their proven reserves, on consumption and production patterns, one can categorize them into the following three categories:

a) Self-sufficient provinces: Those provinces have enough production to cover their own demand on energy and also export part of their production. The caps on production set by the Government however in most cases will force those provinces to import coal from foreign or domestic sources as their demand is higher year by year and there are not many alternative sources of energy available.

b) Importing provinces: Those are provinces that are densely populated and do not have high production of coal either due to lack of resources or due to environmental reasons. They are usually close to large exporting provinces and they are highly dependent on logistics efficiency to cover for their increased demand. Despite major political will, the percentage of coal in their energy mix will remain around 70% in the short term future, suggesting that their demand for imported coal can only increase. The thermal and steel industries situated at those provinces are usually not flexible on pursuing alternative sources of energy and coal remains their number one choice of fuel.

c) Exporting provinces: Those provinces are currently situated in the northwestern, central and northern part of the country. Xinjiang, Inner Mongolia, Shanxi and Shaanxi are the major exporting provinces. They are not that densely populated in comparison with the importing provinces and therefore they are in favorable position for production. However in terms of distribution they are at rather unfavorable positions as there is need for major infrastructure developments that will increase their connectivity with the consuming coastal areas

3.7 Past and current pricing policies of PRC

From the early '50s until 1985 coal prices were kept low and were not being adjusted to the market criteria leading the domestic coal industry to operate at discount. That, according to Lu and Reiser (2012), was due to former Soviet Union policy that the Chinese government followed and by which prices of raw materials should be kept low. Passing through a transition period until 2002, above capacity of mines' output was allowed to be exported at market prices until its' final price-liberalization which has led to the current market-oriented state of the coal market in China. However the bargaining power of the major coal buyers – the power companies- has led to binding contracts with the coal producers which firstly find it difficult to keep up with demand and secondly due to the low prices achieved by the buyers in coastal areas of the country, lack of incentive to cope with the increasing demand. That situation, enforced by the bottlenecks and increasing costs in the transportation system of domestic coal led to the 2009 transformation of China towards being a net importer of coal and to its' 2011 taking up of the number one place of coal importers in the world. However, Morse and He (2012) argue that coastal buyers will keep their demand for imported coal at moderate levels for the upcoming years as inland navigation via the Yangtze and Pearl River Deltas along with infrastructure developments will support a self-sustaining Chinese coal market.

3.8 Overview of the 12TH Five Year Plan

Lying at the foundation of economic prosperity for every nation, energy is of high importance for People's Republic of China and especially in the terms that it is defined by Cao and Bluth (2012) in their attempt to examine the challenges of China's energy security. Those terms are reliability, affordability and sustainability. Reliability stands for the security of the nation's supply of energy as this is achieved by domestic production, foreign investments and markets and efficiency and stability of the logistics network of the country. Affordability refers to the availability of energy that can secure affordable for economic development prices, while sustainability implies the friendlier to the environment practices that also promote energy efficiency and therefore affordability and reliability in the energy sector as a total. Despite the fact that the aforementioned three factors of energy security are interrelated and one presupposes the existence of the other, a distinction is given for the purposes of the present thesis, as there is a clear focus on the reliability pillar of energy security.

China's 12th Five Year Plan (FYP), which was published on the 22nd of July 2011, is analyzed at this section in order to attain a better image of the Central Government's overall plan as far as energy is concerned. The part of the FYP that is about the domestic coal industry is in a nutshell a development promotion program on much needed industry changes with two important pillars determining its main factors;

environmental protection and sustainable development. Social stability as well as the country's position and stance in the midst of the global financial crisis were also factors that acted as foundation criteria towards the development of the FYP. China's opening up and reform effort has put the Central Committee of the Communist Party in a position that it should face the country' s fundamental realities and form wisely its' overall development strategy.

Among the FYP's fundamental requirement two are the ones that should be underlined for the purpose of this research in order to give a better overview of the country's policy. Firstly is the promotion of the competitiveness of the manufacturing industry while achieving a balanced development of urban areas and new socialist villages. Secondly, the resource autonomy of China is considered parallel to the establishment of an environmental friendly society that is characterized by sustainable development.

In the pillar of environmental protection and resource conservation the most impressive and related to the present research goals are described at the table that follows:

Table 2: 12th FYP targets

Target	Yearly Change by 2015
Non-fossil fuel usage in primary energy consumption	+11.4 %
Decrease in energy consumption per unit of GDP	-16 %
Decrease in CO_2 emissions per unit of GDP	-17 %
Decrease in emissions of Sulphur Dioxide (SO_2)	-8 %

Source: Full translation of the 12th FYP as understood by the author

At part III of the 12th FYP, an important note underlying the current and future role of the Chinese market and in specific the coal market is made: "Adhere to the new path of industrialization … give play to the comparative advantage of our country's industries in the global economy…"(12th FYP-Full Translation). The fact that the CPC refers to the comparative advantage of the country's industries, paves the way for coastal Chinese buyers to take advantage of the most cost-efficient producers both within the borders of China and in other countries.

The development of mines that operate in a safe manner and the integration of coal resources through the promotion of mergers and reorganizations of large coal mine enterprises are also within the focus of the program. In the spirit of optimization of the country's energy development, energy bases will be or have already been gradually transferred to Inner Mongolia, southwestern China and Xinjiang. The development also of coal bases in northern Shaanxi, Huanglong, and northern, eastern and central Shanxi are among the main development goals of the government; a fact that can be justified by looking at the importance of those regions in the country's coal flow system.

The construction of large scale power grids that will connect the consuming areas with coal power, hydropower and wind power stations transmitting up to distances of 200,000 kilometers is in the priority list of the 12th FYP, but only to promote the trial phase and accelerate the R&D developments in the field.

From the transportation perspective CCP has made decisive suggestions on the FYP agenda. The acceleration of the construction of coal railway lines is in the first priorities. Coal transport lines from central and south Shanxi and western Mongolia are mentioned specifically as projects of high importance. In the coastal ports' area, the FYP refers to the construction of coal loading ports in the northern part of the country and the development of coal transit and storage facilities in eastern and southern China. As it will be demonstrated at a later part of this assignment, those infrastructure developments are essential for the establishment and enforcement of an energy sufficient coal policy of an economy that has buying and bargaining power on international coal trade.

3.9 Supply and demand imbalances

Most of China's coal is located in the northwestern area of the country. According to published data by the China Energy Statistical Yearbook the Three Xi – Shanxi, Shaanxi and Mengxi (western Neimeng or Inner Mongolia) account for almost 70% of the country's coal reserves and more than 50% of the production. In combination with Xinjiang and Guizhou, the total coal reserves add up to 1014.8 billion tons and yet on the coastal part of China the production is less than 50% of the demand, due to the existence of electricity power plants and industrial areas. Namely Shandong, Guangdong, Hebei, Zhejiang and Jiangsu attempt to fill in the "coal gap" by transporting it from the northwestern part of China mainly via truck and rail to the northeastern ports of Bohai Bay and from there via short shipping or by importing from mainly Australia and Indonesia to the southern ports of Guangzhou.

According to Tu and Reiser(Tu & Johnson-Reiser 2012) 89% of Chinese coal resources are gathered in 12 provinces that are located in the west of Dacing-Anling –Taihangshan- Xuefengshan mountain series and include the aforementioned provinces along with Ningxia, Gansu, Xinjiang, Sichuan, Guizhou, Yunnan, Chongqing, Tibet and Gansu (Figure 1). Reserves are also located in Northern provinces including Beijing, Tianjin, Hebei, Liaoning, Jilin and Heilongjiang. The Industrial organization of the Chinese Coal Industry has accurately determined that the differences in the resources north and south of the Kunlunshan-Qinling-Dabienshan series of mountains determine the coal transportation patterns.

Figure 5: Coal Reserves in China

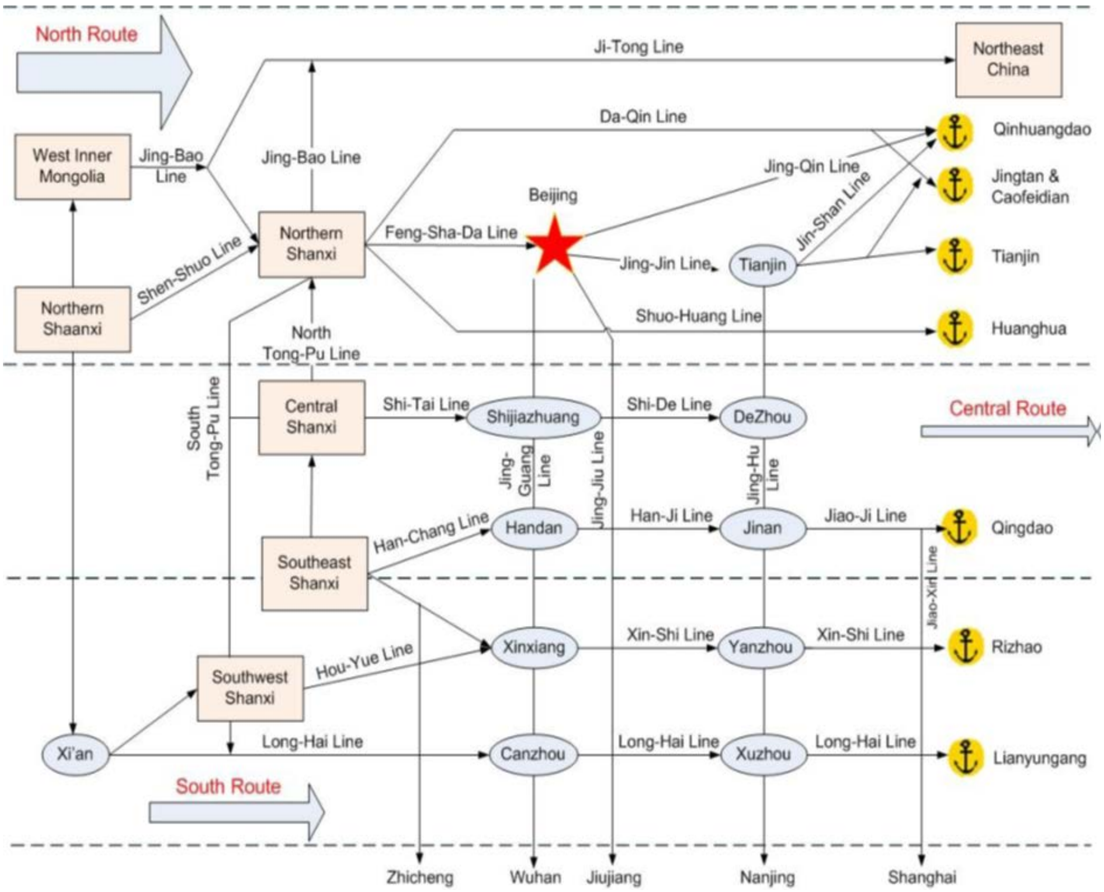
Source: Tu & Johnson Reiser (2012); Map adjusted by author to include provinces

3.10 The Transportation Corridors

3.10.1 Rail

Originally identified in the literature by Sagawa (2003) and Tu (2012), the transportation corridors of coal have as starting point the aforementioned 3-Xi region and are directed towards east and southeast China. The majority of coal is transported from west to north and south, accounting for 75% of transported tonnage and the remaining 25% is transported via the west-east corridor with a 4% of that including moves from east to west (Duan, 2007). The majority of railway lines can be attributed in one of the following three identified routes : a)North route, b)Central route and c) South route (Tu & Reiser, 2012). According to the diagram NUMBER provided by Stanford researchers along with press reports and government announcements after 2009 the table below gives an overview of the basic railway lines per route.

Figure 6: Main Railway Routes and ports of discharge diagram



Source: As created by Tu & Johnson-Reiser (2012) based on data by (Sagawa et al.,2003), China's Ministry of Railways (2008)

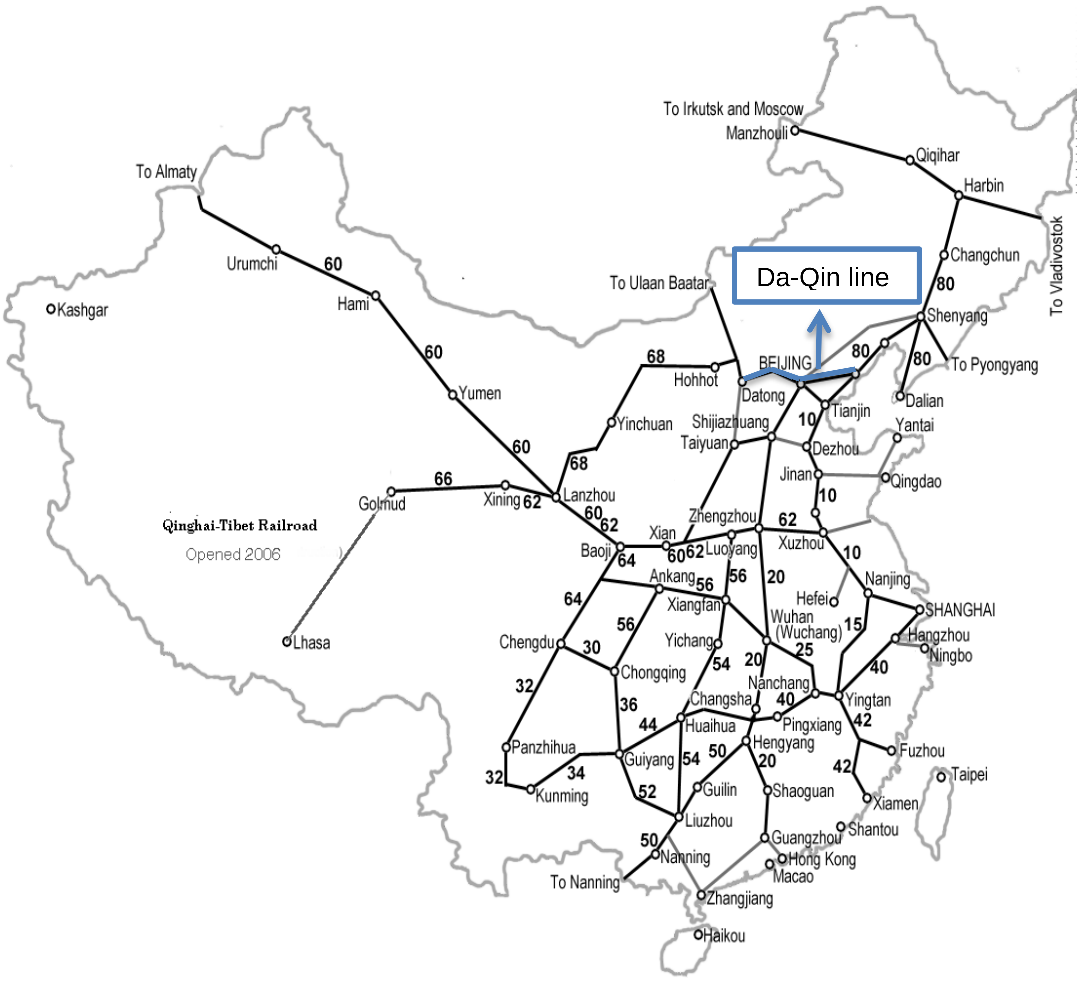
Table 3: Major Railway Routes

Destination - Routes	Railway Lines
North Route lines:	Feng-Sha-Da, Da-Qin, Shuo-Huang, Ji-Tong, Jing-Yuan
Central Route lines:	Shi-Tai, Han-Chang, Tai-Jiao
South Route lines:	Tong-Pu, Long-Hai, Hou-Yue, Xi-Kan, Xiang-Yu

Source: Author's research based on MOR and various internet sources.

Daqin railway line (Figure 7) is identified as being the most important for coal transportation, accounting for almost 1/7 of the total volume transported. Its' final destination, Qinhuangdao port, is the major coal port of the Bohai Bay and is the main port short-sea shipping of coal, originated by Shenhua and Yitai Groups. From Qinhuangdao port, coal produced in the Three-Xi areas reaches Shanghai, Zhejiang in the eastern part of China and Guangzhou, Fujian and Shenzhen at the southeastern part of the country. The existing capacity however is not sufficient to cope with the increased demand and volume transported and therefore severe bottlenecks have been caused. To tackle with the problem, in 2008 the Chinese Government announced an expansion of Daqin's capacity to reach 400Mt along with the construction of a new dedicated line in the Middle Route from Xinxiang in Shanxi to Rizhao port in Shandong, adding an extra 200Mt in capacity. (Snxcoal)

Figure 7: Chinese Railway System



Source: Ministry of Railways, updated map as of 07/2014

Table 4: Throughput of major lines (Unit: Million tons per year)

Route / Line	From	To	2009	2010	2011	2012	2013	2014
Northern Route			564	585	608	671	686	700*
Da-Qin Line	Datong	Qinhuangdao	330	340	345	387	390	400*
Shuo-Huang Line	Shenchina	Huanghua	149	160	172	183	190	190*
Jing-Yuan Line	Beijing	Yuanping	20	20	26	28	28	30*
Ji-Tong Line	Jininan	Tongliao	15	15	15	18	18	18*
Feng-Sa-Da Line	Fengtai	Datong	50	50	50	55	60	62*
Middle Route			98	107	110	115	119	130*
Shi-Tai Line	Shijiazhua	Taiyuan	90	95	98	100	104	110*
Han-Chang Line	Handan	Changzhibei	8	12	12	15	15	20*
Southern Route			210	238	238	263	265	268*
Tai-Jiao Line	Xiuwen	Jiaozubei	70	80	80	90	90	90*
Hou-Yue Line	Houma	Yueshan	120	130	130	140	140	140*
Xi-Zheng Line	Xian	Zhengzhou	11	15	15	18	18	20*
Xi-Kang Line	Xian	Ankang	5	7	7	7	9	9*
Xi-Nang Line	Xian	Nanjing	4	6	6	8	8	9*
Total			**872**	**930**	**956**	**1049**	**1072**	**1098**

*Estimations of the author according to MOR

Source: Continuation of similar table at Tu & Johnson-Reiser's paper on the industrial organization of Chinese coal (2012).

3.10.2 Major ports

The major destination of the southern railway routes are the N-7 coal ports (Northern Seven). Those ports connect the northern production to the southern coastal consumption areas. The N-7 Ports account for 90% of coal sea transportation and are namely:

a) Qinhuangdao, Jintang and Huanghua ports in Hebei.

b) Tianjin port in Tianjin.

c) Qingdao, Rizhao and Lianyungang ports in Shandong.

Those ports are mainly the destination of specific producing provinces. Most of the coal from Shanxi and Inner Mongolia is transported to Qinhuangdao Port, while the coal from Shaanxi goes to Tianjin and Huanghua Ports and the Shandong produced coal is being delivered to Rizhao Port. From those ports the coal is transferred to the eastern and southern coastline of China. The major discharge ports are Shanghai port, Ningbo, Zhoushan and Guangzhou ports(Appendix Figure one).

3.11 Other modes of Coal Transportation in China

Barges

As underlined by the 12^{th} Five Year Plan of PRC, inland navigation is of high importance for transportation of goods, especially within the provincial territories that extend along the coasts of Yangtze river (PAPAPOMPI STO 12^{TH} 5YEAR PLAN).As Tu (2012) has underlined in order to emphasize the importance of inland navigation for the domestic coal industry, almost 12.8% of 2009 output of coal was transported via barges that year. The percentage of coal transported via inland navigation went up to 12.5% and 13.2% for 2011 and 2012 respectively according to the National Agency of Statistics annual reports on transportation proving the increasing role of inland waterways to the coal transportation of China.

The main characteristics and major inland coal ports and routes as described by researchers and as per author's estimation are analyzed below:

<u>Yangtze River:</u> Chongqing, Yueyang, Hankou, Jiujiang , Wuhu, Zhicheng, Yuxikou and Pukou

<u>Jing-Hang Great Canal:</u> Wanzhai, Rizhou, Mengjiagou and Shuanglou

Wuhan Port is the intersection port of coal transported via Jing-Jiu and Jing-Hu lines towards the Jing-Hang Great Canal along with Zhicheng, Hankou, Yuxikou and Pukou (Tu & Johnson-Reiser 2012) which are all Yangtze River ports. Despite the estimated increases in inland coal ports' handling charges and Yangtze River freight rates (Li, 2008), they still provide a competitive and much cost-efficient solution in comparison to transportation via trucks.

Road

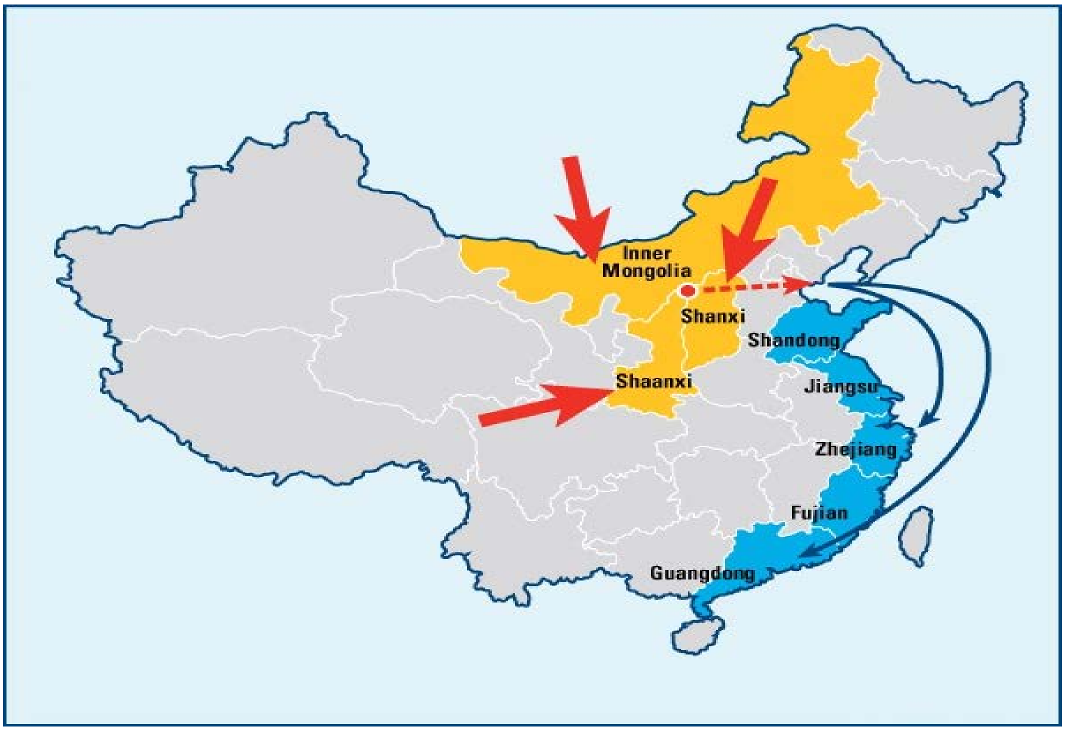
Despite the projected decrease in coal tonnage transported via trucks (12^{th} Five Year Plan) due to the environmental unattractiveness and high costs of the mode, capacity constraints in the rail network as well as the availability of highway connections have enabled coal transport via truck to surpass the 500km threshold, reaching even 638km (Datong – Qinhuangdao). Due to the important role of truck transportation, 20% of the coal flows analyzed by Mou and Li (2012) in their spatial analysis of the Chinese coal flow, had to be adjusted in order to cater for any interpretation errors.

3.12 Coal transportation Bottleneck; geographical identification

Wood Mackenzie stresses out in a 2012 report that transportation infrastructure is the key towards the increase of the domestic trade of coal in China. That is due to the severe bottlenecks created in the transportation system and mainly, as it is mentioned in the introduction of this thesis, at the northwestern part of Daqin line. Tu and Reiser (2012) among other researchers and market analysts attribute the electricity problems of 2011 in the Yangtze River Triangle to the low coal transport capacity of the railway network of China. The lack of dedicated southbound railway lines and the limited capacity of the existing lines are identified as the major reasons for the transportation bottleneck. Most of the coal produced in the north-eastern areas of China is transported via rail and truck (about 20% according to Mou and Li (2012)) towards the Bohai Bay to reach its final destination to the coal ports at the southeastern coastline of China via short-sea shipping.

The importance of rail to coal transportation is easily identified by the increased amount of coal transported every year since the early 80's. However the annual increase in of coal output of the Chinese mines is estimated at 5.3%, comparing to a 4% annual increase of rail transportation. That implies a bottleneck on the supply chain of China's coal, since the only efficient way to transfer coal from the production areas at the northwestern parts of the country towards the southeastern consumption areas would be rail

Figure 6: Bottleneck point



Source: Deutsche Bank

Mou and Li (2012) attribute some of the most severe traffic jams in the history of China along with high number of road accidents to the forced use of trucks for coal transportation due to capacity constraints in the railway system. Moreover they predict that the future is not any more optimistic due to the higher rate at which China's coal consumption increases comparing to the transportation tonnage capacity. It is noteworthy that studies conducted before 2000 by researchers such as Kuby et al.(1995) and Todd and Jin (1997) on the coal transportation network of China tend to underestimate the increased demand rates of China due to its transformation into a market-oriented economy.

A forecast on the coal transportation per mode in China that was conducted by Tu and Morse (2012) underlines the dominance of rail as the only efficient way for domestic coal to reach the southern and western coastal regions of the country. Specifically, it is estimated that by assuming an annual increase of 2.3%, coal tonnage by rail will reach 3GT by 2030, while road mode will only act as supplementary due to the increased fuel costs and environmental awareness of the central government.

China ranks third in the world, after Russia and the USA, in railway length with a total 103 thousand km of rail lines (World Bank). The freight throughput is more than 25% of the world's total while the rail length barely reaches 10% of the world's total rail length. That implies a heavily congested system and if one takes into consideration the small percentage of cargo handled by local railway (around 8% according to World Bank data) the lack of competition is eminent.

3.13 Major developments and expansions in China

Despite the completion of the Three Gorges project that has created new paths for inland navigation and has increased the depth and length of several unapproachable earlier areas the major problem of China's coal transportation lays on railway infrastructure. Despite the fact that port infrastructure has expanded to cater for the increased throughput due to shot-shipping transfer of coal and imports at the southern coasts of China, the main problem still is on the railway infrastructure capacity.

Inner Mongolia's coal production of high calorific value coal has been focused mainly on supplying the coastal provinces and without much success due to bottlenecks. Apart from the Da-Qin railway expansion to handle 400Mt per year, a different line that will connect north to south and will have 1847 km length has been proposed by the major coal and railroad interests of China. Being a part of the 12th Five-year Plan, the line will stretch from Erdos to Hubei and Hunan provinces ending in Jiangxi (China Economicnet, 2012).

3.14 Major suppliers of coal

Due to the price difference of domestic and foreign coal in combination with the aforementioned reasons related to governmental policies and regulations, the imports of coal have spiked the last 5 years. Australia and Indonesia are the two main coal suppliers of Chinese demand, with Russia being the third most important and the country with the highest growth rate of Chinese exports among them. Until the first quarter of 2014, Australia had exported to Chinese ports 37.9 Mt, Indonesia 24.5 Mt and Russia 12.2 Mt. In 2012, Russia held the fourth position among the top exporters of coal with a value of exports at 13 billion USD after Australia, Indonesia and USA which accumulative accounted for 64.4% of the world exports (UN COMTRADE). China, along with Japan, India and Republic of Korea accounted for 58.8% of coal imports in 2012, with PRC noting a record 63.8 of average import increase between the years 2008-2012.

3.14.1 Russia

Due to the large competition in the European market and the increasing import market of China, Russia has diverted focus towards the Pacific trade of coal. However it is difficult to be competitive due to high costs of inland transportation towards its Pacific ports. (Cornot-gandolphe 2013). Russia has been confronting the obstacle of high transportation costs, increasing Chinese demand and high competition by Australia and Indonesia via three ways: a) Improving its rail infrastructure system. b) increasing its' coking coal reserves as its' demand is also increasing c) Promoting deals with neighboring countries that lead to the building of cross-border dedicated railway lines and terminals and result to competing FOB prices for its' coal.

According to a 2009 Wood Mackenzie report on the future of Russian coal exports, it is expected that the Russian coal suppliers will move beyond their margin due to rising charges of rail and ports. Therefore a tighter control of the infrastructure charges is of paramount importance to the Russian supply of coal to China and the Pacific in general.(Wood Mackenzie, 2009)

<u>Coal production</u>

Russia is the second largest coal holder after USA, with 68 billion tons of hard coal reserves and 91 of lignite reserves. Its' main coal deposit is the Kuznets basin in the Kemerovo region in Siberia followed by the Kansko-Achinsk basin in the southern part of Krasnoyarsk region. Those two basins dominate the coal production of Russia with a 75% of the country's output (Cornot-gandolphe 2013)due to their location near the Trans-Siberian railway (IEA, WEO 2011). Increasing Chinese demand of coal along with the strategic importance of coking coal exports in particular, have let to investments by Mechel, Severstal and other major players of the Russian coal market to additional mines and railway lines, targeting the Asian market.

Infrastructure developments

According to the State Duma Committee for Energy chairman Ivan Grachyov's statements of late 2013, Russia expects to increase its' coal exports to China and to countries in Southeast Asia by improving their port and rail infrastructure. Also during the 10th meeting of the bilateral energy committee of Russia and China in Beijing, on October 2013, the will of China to increase Russian coal imports was clearly stated (Lye Chang, 2013). A month earlier at the same year the 17th meeting of a Russian – Chinese commission for transport cooperation was concluded in Beijing. Among the main projects that were agreed in the spirit of integration of the countries' transport network are the following:

- Railway bridge on Nizhneyeleninskoye – Tunjian section.
- Hunchun – Makhalino railway capacity increase
- Zarubino port modernization
- Development of Murmansk transport hub
- Capacity additions of the railways connecting Kuzbass with the port of Sea of Japan
- Capacity additions to the railway connection between Nakhodka and Port of Vostochny

The main Pacific ports that are used for coal exports towards Asia and mainly China are:

Vanino port

Vanino port is the largest transport hub of Khabarovsk Krai and the second largest Pacific coal port of Russia. It is located in the north west shore of Vanino Bay. It is the final point of the Transibirean and Baikal-Amur railway lines and therefore plays an essential role in the country's coal exports. It can accommodate vessels up to 40.000 dwt with 11.3m draught and has in total 22 cargo berths. JSC "Daltransugol", a subsidiary of OJSC "SUEK" is operating a coal terminal at the port with a capacity of 12 million tons while Mechel has also one coal terminal with a 25 million ton capacity. Despite the fact that the current railway leading to the port cannot cope with the increased capacity and demand, it is in the development program of Russian Railways and Baikal-Amur line to increase capacity at 30 million tons per year. (RHDHV; 2010).

Vostochny port

Vostochny port in located in the deep-water bay of Vrangel at Primorsky Krai and has a 20km distance from Nakhodka, the end of the Tran-Siberian railway. It is the deepest port of Far East Russia with a draught of up to 22 meters and year-round navigation, while it can also accommodate vessels of 150.000 tons deadweight . JSC “ Vostochny Port” operates a coal terminal and a universal terminal with a total capacity for coal transportation of 23.5 million tons per year. Similar to Vanino port’s railway connection, capacity upgrade projects that will cater for the increasing demand have already been commenced according to Government’s guidelines. It is noteworthy that the Russian Institute of Economy and Transport Development has stated that RZD will have to double its’ funding for infrastructure improvements in order to accommodate the growing volumes of transported coal from Kuznetsk Basin to Vostochny.

Bolshoy Kamen terminal

A project of SDD holding on building a coal terminal at Sukhodol bay, near Vladivostok, is under development.

Posyet port

A capacity upgrade that will allow the Commercial Port Posyet JSC to accommodate for 14 million tons until 2015 is currently under development.

Non Defined Location

A terminal with total capacity of 20 million tons per year is planned to be built by the Federal State Unitary Enterprise VO Zarubezhugol in the Far East part of Russia. It aims to allow access to small coal producers and it will probably be built in Vostochny port or Zarubino bay.

Rajin port

Despite not even being close to the capacities of Vanino and Vostochny ports’ terminals it is interesting to mention the Port of Rajin. It is located in North Korea, has a 4 million tons capacity and is the outcome of the cooperation between the Russian Railways Subsidiary RZhD Logistica and the North Korean Ministry of Railways. RZhD Logistica offers transportation of coal CIF to the Chinese ports at rates competitive to the Russian, Indonesian and Australian ports as the outcome of supply chain efficiencies in its transport network.

3.14.2 Indonesia

With 21 billion of coal reserves, Indonesia is one of the leading exporters of steam coal in the world. Bituminous and sub-bituminous coal exported from Indonesia towards China accounted for more than one third of the country's total exports for the years 2009-2012. Due to low production costs and internal transport logistics(Cornot-gandolphe 2013) Indonesia has managed to be China's second coal exporter after Australia. Demand for low calorific value coal from China and India in combination with Indonesia's large low calorific value coal reserves have shaped the dynamics of the current situation in the Pacific region. However, a turn of the markets towards the more ecofriendly and efficient coking coal has led the Indonesian government to promote the upgrading of the quality of its coal.

3.14.3 Australia

Australia is the largest exporter of coking coal in the world, as it accounts for half of global exports. In 2011 it was overtaken by Indonesia as the largest exporter of coal to China but in 2012 it retook the first place, mainly by increasing its' available low calorific value coal resources. Its' reserves are estimated at 43 billion tons (BGR,2012) with Queensland, New South Wales and Victoria holding the country's major reserves. However, Australia struggles with high production costs and lower productivity rates (Cornot-gandolphe 2013), increasing regulatory barriers, taxation and bottlenecks at its railway and port infrastructure which often result to high losses due to demurrage costs. The total handling capacity of Australia's main coal terminals is around 513 million tons (BREE, 2012)

Major Findings

SRQ 1 - 3 :

- Chinese Government intends to increase the infrastructure capacity in the coal transportation system of the country.
- The consolidation of the country's mining industry and production that is expected to affect the supply locations of China.
- China's intentions to increase its' dependence on coal imports are not clear and a shift towards a domestic self-sustainable market cannot be disregarded; different scenarios need to be taken into account while estimating the future coal flows in the country.

SRQ 2:

- The major exporters of coal are Australia, Indonesia and Russia.
- The infrastructure developments in the coal transportation system of Russia imply a potential shift in the Pacific's region and especially the Chinese coastline's coal trade flows towards Russia. A clear view of the capacity upgrades will enable us to estimate the future position of Russia among China's coal exporting countries.

Chapter 4 Transportation Model Analysis

The goal of this thesis is to identify the lowest cost – path for efficient coal transportation in China, taking under account the announced infrastructure developments and the available quantities from foreign producers. Through a Linear Programming (L.P.) model the author will try to identify the most cost-efficient routes that the coal flows will follow given the specific capacity constraints of the railway system, the ports and the Yangtze-river ports. Imbalances in demand and supply will also be taken into account and estimations on production and coal demand will be applied to estimate the future coal flows in PRC.

At this chapter the mathematical process of the construction of the L.P. model will be demonstrated. The parameter and constraints that were incorporated into the model will also be analyzed. A complete presentation of the assumptions taken during the research will be provided along with the limitations that should be kept in mind while interpreting the results of the main application and sensitivity analysis that follow at chapter 5 of the thesis.

4.1 Research approach and method

We use a linear program that will calculate the most efficient routes of coal transportation in terms of cost. Similarly to the research approach of Mou and Li (2012) the basis of the applied Linear Programming model is on two basic principles of energy economics: a) Firstly the demand for coal is rigid; this means that demand must be fulfilled by supply. b) Secondly the key parameter is cost. Since the elasticity of mode choice probability and the market price elasticity of demand for transport of coal range from 1.4 to 2.0074 (Abdelwahab 1998), we can safely assume that time for delivery does not play such an important role comparing to cost. That is because, buyers are very sensitive (elastic demand) on price changes of coal transportation and therefore willing to choose a slower mode if the cost is lower. Apart from situations such a stock exhaustion and supply disruptions, the main determining factor of coal flows is considered to be the cost of transportation.

Capacity at railways and ports will be taken into consideration. The main focus will be placed on announced expansions at railway lines and ports in China and Russia in order to access their impact on coal flows. Yangtze-river's impact to coal flows will be assessed in combination with the pre-mentioned capacity expansions. Additionally, the main supply centers of coal in China will move to northern provinces as coal mines at Henan and Shanxi have reached their Hubbert Peaks(Tao & Li 2007). Xinjiang's role as a major coal provider with coal reserves close to 2.2 trillion tons will also be taken into account.

4.2 Assumptions

4.2.1 Truck Exclusion

The truck mode is excluded from the analysis as it is considered to be economically unviable. Due to the existing bottlenecks it explains approximately 20% of the domestic flows of coal in China but since the purpose of the analysis is to estimate the minimum cost transportation method truck mode is out of the scope. Inconsistencies that might occur at given data on coal trade volumes will be corrected accordingly.

4.2.2 Price differences

A single price for each of the rail, barge and sea modes is used in every country for the purpose of simplifying the calculations for each destination. However the reader should bear in mind the following two important observations:

- The existence of different rail operators and dedicated or mixed railway lines translate into different pricing policies for the rail mode in Russia, Australia, Indonesia and China.
- Price differences between different operators might affect the choice of route for the coal suppliers and buyers.
- Different operators might charge different prices depending on the coal quality, equipment available, demand, tonnage available and several other factors
- The freight rates vary depending on the availability of tonnage, demand for transportation, size of vessel and several other factors that are out of scope of the present analysis but do affect the final buying behavior and transportation patterns of coal in the Chinese market.

The costs used for China are based on Li and Mou's (2012) study on China's coal flows. For railway distances a mean cost of 0.12RMB per ton per kilometer is adopted and for barges and short shipping a cost of 0.04RMB per ton per kilometer is assumed. In a similar fashion a single price of 0.04RMB per ton per kilometer for the usage of sea going vessels arriving from Australia and Indonesia is assumed.

To account for the transportation costs via railway from Russia's main coal basin to Vostochny and Vanino ports a 0.03RMB surcharge is applied to the freight rate prices of 0.04RMB per ton per kilometer for routes connecting Russia and China. The approximate distance from the Kuzbass basin to Russia's Pacific ports is 5,700 kilometers and by dividing that with the average train freight rate (Appendix – Kuzbass to Pacific ports rail freight rates) the author calculated a cost of 0.005

Dollars per ton per kilometer which is converted to 0.03 RMB per ton per kilometer if we use an exchange rate of 1 dollar being equal to 6.15 RMB (11/08/2014).

4.2.3 Thermal and coking coal

The model does not separate between the two qualities of coal. Despite the fact that each type of coal is almost a different market, the demand for both qualities is that high in China resulting to all of each major importers to make investments on both thermal and coking coal mining activities. While initially Australia was the sole provider of coking coal for the Chinese market, Indonesia and especially Russia have made an impressive entrance in the coking coal trade, marking high annual growth rates. It must be noted that demand for high quality coal is not responsive to price changes as it is the case for low calorific value coal. However, given the entrance in the coking coal trade of all the countries in the research, the main goal of the model is to determine the most cost-efficient trade flows under the assumption that demand is met by sole criteria the transportation price.

4.2.4 Future Demand and Supply

According to J.P. Morgan's report on the coal sector of China, a demand growth of approximately 5% per annum is expected until 2015. That is due to the strong dependency of China on coal to preserve its steel production and energy needs. Tu and Reiser (2012) also attribute a slower growth than the previous years (10%) by 2025 due to the lower dependency on coal for electricity generation and the use of alternative energy sources on the industrial sector of China. The availability of scrap steel and the 12^{th} FYP's underlying guideline on environment conservation, on energy source diversification and on resource preservation are also reasons to erode the future demand for coal both on the thermal and the metallurgical sectors. Therefore, He and Morse (2010) predict a conservative 4% annual increase in demand by 2020.

As the purpose of the current research is to estimate the most cost effective routes, the current rate annual increase in supply which stands at 1% (CESY, 2013) will be used to estimate future supply and the JPMorgan outlook will be applied while estimating future demand for China. Apart from that different scenarios will be applied as part of the sensitivity analysis that will include focus of production in Xijiang and Neimeng and increase in demand at the southeastern coastal provinces of China. However the demand-supply gaps of the year 2013 of each Chinese province will be used as the base scenario in the initial implementation of the constructed model.

4.2.5 Australia and Indonesia – adequate capacity & single port

Since the focus of this report lies on the infrastructure developments in Russia and China, Australia and Indonesia are assumed to have adequate capacity at their ports and supply chain networks to cope with the rising demand of China. Despite the fact that this is not the case, as both countries face major capacity challenges (Cornot-gandolphe 2013), this assumption allows the researcher to focus on the Sino-Russian trade flows. It is acknowledged that by assuming adequate capacity, a certain bias in favor of Australia and Indonesia is created. However this is something that should be kept in mind during the interpretation of the model application results allowing for a more optimistic treatment of the Russian export market.

Furthermore, again as the focus of the research lies on the Sino-Russian coal flows, it is assumed that there is one single port at each country. For Australia that port is Newcastle port and for Indonesia it is Tanjung Bara coal terminal. That assumption enables the researcher to calculate the distances in an easier manner as well as to use less data from the Indonesian and Australian side. The downside is that the unit costs for the transportation of coal from different ports might have varied should many ports have been used for each country. However the differences of the unit transport costs between two Indonesian ports acting as origins for China are very small comparing to the differences between port Tanjung Bara (Indonesia) and port Vanino (Russia) acting as origins for Chinese imports of coal. In other words, since the major coal flows can be identified, this assumption does not alter the final results.

4.2.6 Ceteris paribus

Prices of both types of coal are affected by availability, demand, moisture, ash content, sulfur, volatiles, calorific value and several other factors such as policies, taxation, price caps and international treaties. China's import tax, VAT, transaction costs (letters of credit, offices) affect the buying behavior of Chinese coal users. The author assumes a ceteris paribus situation while applying the LP model of this research and does not take under account any external factor other than the cost of transportation.

4.3 Description of the Optimization "Coal Flow" Model

4.3.1 Objective Function

The objective of the provinces in the system that purchase coal from domestic or foreign markets is to minimize their transportation costs. The objective of the system optimization analysis is to determine the optimal route of coal by combining different modes through different nodes of the system subject to certain constraints. The transportation cost is estimated in terms of distance, mode, handling costs and freight rates. However, since there is no unique handling cost for a route and that depends on the mode selected, the two major parameters are divided into transportation cost and handling cost as those are defined by the mode and route applied. The objective function is formulated as follows:

$$Minimize\ Z = \sum_{m} \sum_{i \in N} \sum_{J \in N} x_{ij}^{m}\, c_{ij}^{m} + \sum_{j \in N \setminus i} x_{ij}^{m}\, d_{i}^{m}$$

Indices

i :	Coal supply area
j :	Coal demand area / intermediate node

Decision Variable

x :	Quantity of transported coal

Parameters

c :	Transportation cost
m :	Transportation mode
d:	Handling cost
D:	Demand of coal
S :	Supply of coal

As explained above, i is the coal supply area, j is the coal demand area, m is the transportation mode, e.g. water, rail, train, x is the quantity of coal transported, c is the transportation cost for the distance between the two nodes i and j as this has been calculated by the author by multiplying the distance between i and j with the applicable freight rates (Table 2 – appendix) and d is the handling cost. D and S represent the demand and supply of coal respectively.

4.3.2 Constraints

<u>Demand – flow constraint</u>

The demand-flow constraint is based on the principle that each supply area can act as a node of transportation for coal coming from other supply areas and heading to certain consuming areas. In other words, this constraint states that the inflow of certain j node minus the outflow towards a demand area i must be bigger than the demand of coal at node j (Figure 7). For instance, if the node is Shanghai province in China, Shanghai demand must firstly be satisfied and then Shanghai can act as a node for transportation of coal to other coastal areas. It is formulated as follows:

$$\sum_{m}\sum_{i\in N\backslash j} x_{ij}^{m} - \sum_{m}\sum_{i\in N\backslash j} x_{ji}^{m} \geq D_j \;\; \forall j$$

Supply – flow constraint

Similarly to the demand – flow constraint described above, the supply – flow constraint notes that at a supply area i that acts as node the outflow minus the inflow should not equal or bigger to the supply quantity of the node I (Figure 7). This constraint allows for a supply area to act also as a node for coal coming from other nodes in order to satisfy the demand of coal in China utilizing the lowest-cost transportation routes and modes. It is formulated as follows:

$$\sum_{m}\sum_{j\in N\backslash i} x_{ij}^{m} - \sum_{m}\sum_{j\in N\backslash i} x_{ji}^{m} \leq S_i \;\; \forall i$$

Positive- flow constraint

The quantities x transferred are referred to coal and cannot by definition take a negative value. In other LP models applied to estimate the optimal transportation cost of materials(Chang 2008), negative quantities represent the outflows of an area. However in this model the quantities of coal exported and demanded have been defined as coal gaps, implying the difference between production and demand of coal in absolute terms. Therefore the positivity of the quantities transferred is guaranteed by the following constraint:

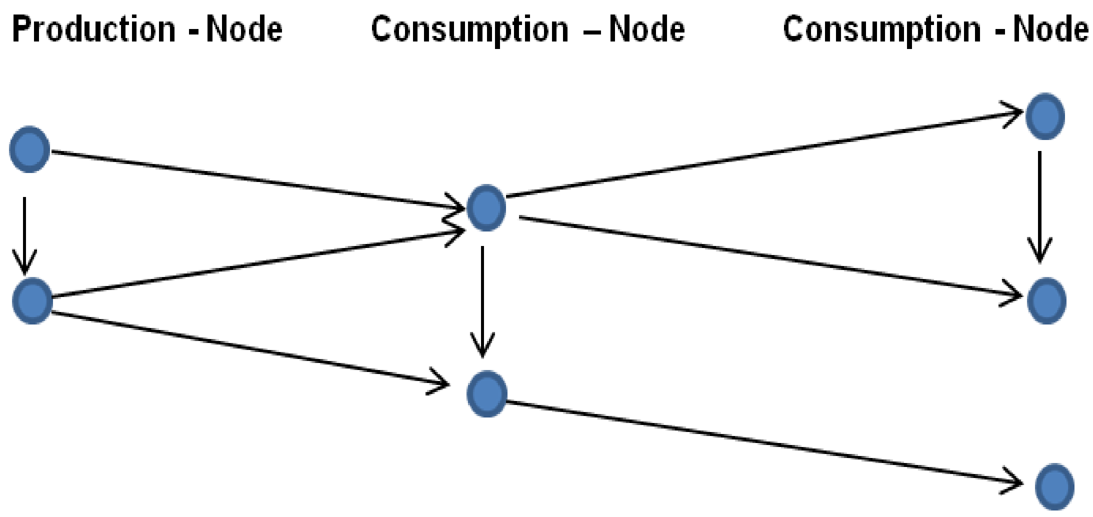
$$x_{ij}^{m} \geq 0$$

Capacity constraint

In order to assess the effect of different port and rail capacities in the system and at the same time evaluate the efficiency of certain capacity expansion projects a capacity constraint is added in the model. For each node of transportation and mode used there is a certain capacity limiting the annual throughput of coal that can be transferred. The capacity is represented by parameter q and the capacity constraint is formulated as follows:

$$x_{ij}^{m} \leq q_{ij}^{m}$$

Figure 9: Schematic representation of the flow constraints



4.4 Limitations of the research method

4.4.1 Technical limitations

The present research, following the footsteps of Morse and He (2010), does not take into account any technical limitations to imports that might prevent a possibly more profitable option of full switch to imports. The power plants' boilers' design to burn specific types of coal and their ability to blend different coal qualities is carefully designed to apply to domestic coal specifications limiting a possible full switch to imported coal.

4.4.2 Data disbursement - limitation

The data derived by the Statistical Yearbook of China on demand and supply of coal are at provincial level but are representative of the whole demand and supply across each province. Similar to the approaches of Mou and Li (2012) and Chang (1980) the author assumes that the demand and supply is concentrated on the capital of

each province. This assumption enables the author to use the distances between the capitals of each province and the foreign and domestic ports for the purpose of applying the created minimization model. For those provinces that have a sea port or a river port the demand and supply are assumed to be concentrated in the city that contains the port (which in many cases is also the provincial capital). .

4.4.3 Classification of coal-limitation

Another data related issue that had come up during the data mining process for this research is that the classification of coal in China follows different standards than Europe, U.S.A., Australia and Indonesia. Similar to the Russian classification system the People's Republic of China is based on volatile matter. The Chinese coal type nomenclature is not consistent with the ISO 11760:2005 and uses the old established terminology of gas coal, fat coal, lean coal and long flamed coal. All coal is divided into brown coal, bituminous coal and anthracite (Thomas, 2012). The differences in coal classification along with the difficulty on finding data on separate types of coal consumption and supply led to the use of a data including all types of brown and bituminous coal in an aggregated form.

4.4.4 Data sources and data distortion

The data used in this research are derived by the following sources: Premium China database and Chinese National Bureau of Statistics for coal consumption and production in China for the year 2012. Royal Haskoning DHV's data on expansion projects in Russia were used to derive the expexted capacities of certain ports.The Table of Distances between Main National Railway Stations for established railway lines in China as this was illustraded by Mou and Li (2012) and internet sources for expected ones , Table of Distances for Domestic Sea Routes and Table of Distances of Ports in the Yangtze River for distances in China (Mou & Li 2012) along with Dataloy for distances between ports in the whole system.

China's Statistical reporting has been under scrutiny for its' reliability as it has reported by researchers to have contradictive (Mou & Li 2012) and even false data(Tu & Johnson-Reiser 2012), especially on coal production.. According to Tu and Reiser (2012) since the establishment by the 12th FYP of production caps set on provincial level as part of the plan's safety and environmental protection emphasis, underreporting of production along with underreporting of fatalities in the industry have been quite an important issue.

According to independent researches, for the period 2011-2012 more than 250,000 fatalities had been noted in Chinese mines (Tu & Johnson-Reiser 2012), while in 2012, Inner Mongolia, Shanxi and Shaanxi underreported their coal outputs by 18 percent, 12 percent and 16 percent respectively (China Coal Transport and Distribution Association, 2012). The still large numbers of TVEs that operate often small, unsafe and polluting mines add to the statistical deterioration of the coal industry of China.

Various recommendations have been made to counter for the aforementioned problems with the most essential and promising according to the author being the following:

- Set production and consumption caps only on metropolitan areas, where the air quality is trending political and social issue.
- Legally binding coal caps for the metropolitan and coastal areas.
- Reorganization of the statistical reporting system by assigning independent, non-governmental agencies.
- Closing down of TVEs.
- Encouraging of coal imports.

Since it is more relevant for the purpose of this research, the phenomenon of statistical underreporting is acknowledged by the author. However there is not a suitable solution to account for the statistical distortion. The differences on between actual and official provincial production and demand amounts could be significant enough to alter the optimal solutions as provided by the created model's applications. On the other hand, multiple scenarios were run along with one that contains different demand and production volumes not only to account for the statistical distortion but also to assess the optimal routes on different supply and demand patterns that are most likely to take place in the future years

4.5 Application of the model

The Linear Programming model described above was applied by using AIMMS software. AIMMS stands for Advanced Integrated Multidimensional Modeling Software.

In this research AIMMS applied the CPLEX 12.6 solver to derive the optimal solution for the minimization of the given objective function. At the base case scenario (4.2 No-constraints model) AIMMS took approximately 0.02 seconds to process approximately 3304 constraint variables and 3268 cost variables and lead to an optimal solution.

According to data on provincial consumption and production of coal provided by the Chinese Bureau of Statistics that were found on the China Premium Database and other sources mentioned above, we divided the Chinese provinces into those that have a coal gap and import coal to cover it and those that have coal surplus and are exporting provinces. The table below indicates that division as it was imported into AIMMS while the values are provided at "Goal-gap Table" in the Appendix:

Table 5: Province division in AIMMS

Set	Parameter	Province
Nodes	Supply (i)	Anhui, Henan, Shaanxi, Gansu, Qinghai, Xinjiang, Sichuan, Guizhou, Yunnan, Shanxi, Inner Mongolia, Ningxia
Nodes	Demand(j)	Tianjin, Beijing, Liaoning, Heilongjiang, Shandong, Jiangsu, Shanghai, Zhejiang, Jiangxi, Fujian, Hebei, Hunan, Hubei, Guangxi

The capacity constraints for each origin and destination were set in an aggregated form in order for AIMMS to identify them. For instance, in the case of the Da-Qin railway line, the yearly capacity of 400MT was divided between the two possible connections of Inner Mongolia and Beijing and Inner Mongolia and Tianjin.

Some of the provinces of the above table have sea ports, river ports or are even connected with railway lines to other provinces. To import that information into AIMMS, the parameter “UnitTransportCost” was introduced. This parameter was basically the cost for a unit to be transported between two nodes i and j. In every possible connection between the nodes the transportation cost was imported according to the tables of distances provided in the appendix and the freight rates that were assumed (4.4.2). For those pairs of nodes that there was no connection with any mode the “’UnitTransportCost” was set extremely high “9999999” so that they would not be taken into consideration by the minimization model.

Major Findings

SRQ 1 – 3:

- A linear programming model is suitable for solving a transportation problem. Applying AIMMS will enable us to account for capacity changes in China and Russia.
- The assumptions that needed to be taken were stated and are:
    - The exclusion of road mode
    - The single freight price for each mode
    - No distinction between thermal and cocking coal
    - Future demand and supply projections according to JPMorgan's estimates
    - Australia and Indonesia have adequate capacity and are represented by one port in each country.
    - Ceteris paribus; no external factors except the transportation cost are taken into account
- The shortcomings and limitations were stated and will be taken into consideration while interpreting the results. Those are:
    - Technical limitations: a full switch to imported coal is not an option.
    - Date disbursement: supply and demand is concentrated in the capitals and ports.
    - Data distortion: Chinese statistics are under scrutiny.

SRQ 4:

- The input of transportation cost into the model and AIMMS is of vital importance for identifying the optimal solution. Modes that could not be physically connected were assumed to have infinite transportation costs.

Chapter 5. Model implementation and findings

In order to assess the model's alignment with the current situation of the coal trade in China a "current situation" scenario is applied at the beginning of this chapter. The main trade flows are identified at a map created that will act as the reference point for the different scenarios that are run. To answer sub-research-questions 1 to 3 a scenario called "no-constraints model" will be applied. In order to answer sub-research question 4 a scenario that will involve changes in the supply patterns of coal will be applied at the final part of this chapter.

5.1 Current Situation scenario

5.1.1 Characteristics

We firstly apply the minimization model on the status of the current coal transportation system in China. In that way it is possible to test how the structured "coal flow" minimization function fits to the existing trade flows. The current situation of the Chinese coal market as understood by the author in the scope of this research is characterized by the two following major criteria:

- Limited capacity of Russian ports: This is attributed to bottlenecks in the railway /system and actual limited capacity of Vanino and Vostochny ports comparing to the competition originated by Chinese, Australian and Indonesian production.
- Limited capacity of Da-Qin railway line: As described at section 3.12 of the thesis the limited capacity of Da-Qin railway line is the origin of the major bottleneck in coal transportation of China.

5.1.2 Application of the model

In order to incorporate the above constraints into the model, the Da-Qin railway capacity was entered in the form of a capacity constraint in a cumulative order for all exports leaving Inner Mongolia and heading Beijing and Tianjin, while the Russian ports' capacity was entered again in a cumulative function for all the destinations of Russian coal exports. That way the general capacity constraint could be captured, but it was done so in a cumulative function and not on the basis of destination frequency due to lack of data. That might have resulted in slightly balanced results but nevertheless indicative of the general coal flows.

5.1.3 Analysis of findings by mode / Discussion

Firstly, the most cost-efficient routes are demonstrated in the table below. That is achieved by identifying the major intermediate nodes in the coal transportation system, as they were extracted via the application of this scenario.

Table 6: Major intermediate nodes – current situations scenario

Province	In	Out
Tianjin	378.2 (rail)	193.6 (sea)
Shandong	408.5 (rail)	182.9 (sea)
Hebei	367 (rail)	171.5 (sea)
Beijing	57.9 (rail)	40.1 (rail)
Hubei	184.7 (rail)	35.6 (river)

Source: Author's Calculations Unit: Million tons per year

A more detailed description follows by demonstrating the coal flows of each mode. This will allow us to identify the most cost efficient routes for the scenario.

<u>Sea mode</u>

According to Table 3, Jinan port in Shandong province is used for transporting coal that comes mostly from Shanxi province and partly even from Inner Mongolia, since the Da-Qin railway cannot accommodate for the transportation of coal to the Bohai bay ports; an otherwise more efficient destination.

Table 7: Estimated sea coal flows – current situation scenario

Out / In	Jiangsu	Shanghai	Zhejiang	Fujian	Guangdong	Guangxi	Total
Tianjin	15.7	43.6	47.8	36.8	49.8		**193.6**
Shangdong	166.7	0.0	16.1				**182.9**
Hebei	45.0	14.9	45.0	27.5	38.6		**171.1**
Guangxi					22.2		**22.2**
Vostochny			19.4				**19.4**
Vanino			15.3				**15.3**
Australia					72.5		**72.5**
Indonesia					27.5	38.2	**65.7**
Total	**227.4**	**58.5**	**143.6**	**64.3**	**210.6**	**38.2**	**742.7**

Source: Author's calculations Unit: Million tons per year

Tianjin port's important role in the domestic coal flow is well captured by the applied model as we notice that all coastal provinces are partly or wholly supplied by it. Zhejiang province's demand is mostly covered by Chinese coal, while Russian ports provide for the part that cannot be found at a competitive price in the domestic market due to logistic bottlenecks. The same situation is pictured in Guangdong and Guangxi provinces with the difference that Australia and Indonesia cover either for the biggest part or the whole coal demand due to proximity and most competitive transportation costs.

Rail mode

With a total of almost 1.7 billion tons transported via rail, the Chinese Railway system is under full capacity according to its' current limits. The biggest part of coal flows originates from Shaanxi province via Xi'an towards Hubei province and Hebei province's ports. Bohai Bay's ports are a focal point of coal distribution since they receive coal also from Inner Mongolia. More than 370 million tones are transferred there to serve the coastal provinces' coal demand. We notice that Xinjiang province's coal production is not transferred since it is not cost-efficient to do so due to capacity restrictions at the Da-Qin Line and due to the fact that it is less costly to import coal from Shanxi and Shaanxi provinces towards the coastal, coal demanding provinces.

Table 8: Estimated rail coal flows – current situation scenario

Out / In	Shangdong	Lioning	Jilin	Jiangsu	He'nan	Hubei	Sichuan	Total
Tianjin	131.6							**131.6**
Beijing	40.1							**40.1**
Heilongjiang	36.0	116.2	47.5					**199.6**
Shaanxi				29.1	57.8	184.7	18.7	**290.4**
Yunan							5.3	**5.3**
Shanxi	200.8							**436.1**
Total	**408.5**	**116.2**	**47.5**	**29.1**	**57.8**	**184.7**	**24.0**	
Out / In	**Gansu**	**Hu'nan**	**Guangxi**	**Hebei**	**Tianjin**	**Beijing**	**//////////**	**Total**
Guizhou		30.5	14.9					**45.4**
Shanxi				367.0				**567.8**
Inner Mongolia					378.2	57.9		**436.1**
Ningxia	5.2							**5.2**
Total	**5.4**	**30.5**	**14.9**	**367.0**	**378.2**	**57.9**		**1721.8**

Source: Author's calculations Unit: Million tons per year

River mode

By adding the Yangtze River option to the application of the model, it is noticed that Jiangxi province's coal demand is fully covered via inland navigation. Anhui's production and Shaanxi province's coal that has been transferred via rail from Xi'an to Hubei are finally transferred via river to Nanchang. Hubei's favorable position along Yangtze river and rail connectivity with Shaanxi province have to be noticed at this particular part as they are indicative of its' future role.

Table 9: Estimated river coal flows– current situation scenario

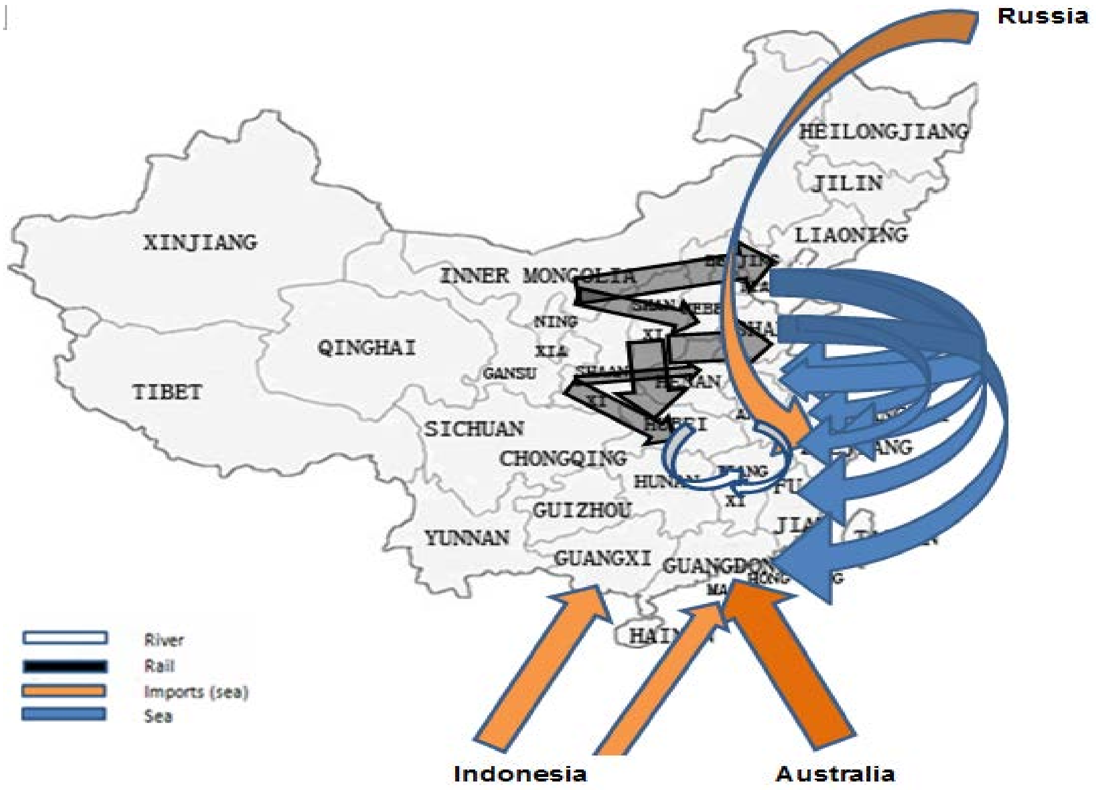
Out/In	Jiangxi
Anhui	2.8
Hubei	35.6

Source: Author's Calculations   Unit: Million tons per year

Evaluation of the model's alignment with the current status quo of coal flows

A characteristic that justifies one of the reasons for the increased infrastructure investments in Russia is that at this application of the model it stands at the third position of the most efficient route origins for China's coal providers; a status that changes in the following applications of the "coal flow" model in which the constraints are relaxed to reflect the infrastructure upgrade of Russian ports.

Figure 10: Coal flows under current situation scenario



Source: Author's estimations

5.2 No constraints scenario – base case

5.2.1 Characteristics

At this case the model is applied without the capacity constraint restrictions at railway lines and ports. The only criterion by which the optimal coal flow was calculated is the transportation cost.

In order to estimate how the capacity upgrades in the Chinese and Russian infrastructure will affect the coal flows in China we assume that there are no capacity restrictions on the importer's and exporters' side due to infrastructure developments sufficient to cope with the increased throughputs. Therefore the main criterion for the decision of the optimal routes is the transportation cost.

5.2.2 Application of the model

In order to incorporate the above criteria into the model, the capacity constraint of each destination and origin at the model used was set at a very high number – far exceeding the demand and supply numbers. Thus AIMMS, the software used to solve the minimization equation considers the capacity constraint requirements fulfilled. This application of the model does not resemble reality as capacity constraints exist and will continue to exist since it is impossible to have unlimited capacity for trade flows at any given place and time. However, it allows the author to estimate the trade flows of coal, if it is assumed that the infrastructure upgrades are sufficient and that capacity is not an issue.

5.2.3 Findings and analysis by mode

Table 10: Major intermediate nodes – base case scenario

Province	In	Out
Hebei Shanghai	342.2 (rail) 94.1 (sea)	143.6 (sea) 35.6 (river)

Source: Author's Calculations Unit: Million tons per year

Rail mode

It is noticed that the main mode is still train which accounts for more than 50% of the coal flows of China. That is representative of the importance of rail infrastructure for PRC, since even at “cost/restriction – free” environment rail still accounts for most of coal transportation.

Table 11: Estimated rail coal flows - base case scenario

Out / In	**Jilin**	**Heilongjiang**	**He'nan**	**Hubei**	**Gansu**	**Sichuan**	**Total**
Liaoning	47.5	48.4					**95.9**
Shaanxi			57.8	149.1	11.4	24	**242.3**
Qinghai					0.2		**0.2**
Total	**47.5**	**48.4**	**57.8**	**149.1**	**11.6**	**24.0**	
Out / In	**Hu'nan**	**Shangdong**	**Guanxi**	**Hebei**	**Beijing**	**///////////////**	**Total**
Guizhou	30.5		14.9				**45.4**
Shanxi		225.7		342.2			**567.9**
Inner Mongolia					17.8		**17.8**
Total	**30.5**	**225.7**	**14.9**	**342.2**	**17.8**		**969.5**

Source: Author’s calculations Unit: Million tons per year

The uneven distribution of production and demand in China make the rail infrastructure developments of vital importance for the domestic coal trade. The upgrading in the capacity of southeastern ports will allow more imports to cover the coastal demand and also alleviate the regional railways from unneeded traffic. As the12th FYP sets caps on the coal production of provinces, the capacity upgrades of the southern ports is considered to be of vital importance, since according to this application of the model those ports will have to cope with increased imports.

Sea mode

Another indication of the results of the model is that coastal shipping from Bohai Bay to cover the demand of northeastern provinces from coal produced in Shaanxi and Inner Mongolia will be gradually replaced by imports from Russia and Indonesia that due to lower transportation costs and economies of scale will be able to cover the whole demand of those regions.

Table 12: Estimated sea coal flows - base case scenario

Out / In	Tianjin	Liaoning	Jiangsu	Shanghai	Zhejiang
Hebei	53	93.3			
Vostochny		118.7	256.6	94.1	143.6
Indonesia					
Total	**53**	**212**	**256.6**	**94.1**	**143.6**
Out / In	**Fujian**	**Guandong**	**Guangxi**	/////////	**Total**
Hebei					**146.3**
Vostochny	64.3				**677.3**
Indonesia		176.3	50.2		**226.5**
Total	**64.3**	**176.3**	**50.2**		**1050.1**

Source: Author's calculations Unit: Million tons per year

Shanxi and especially Hebei region are those that mostly distinguish at this application of the "Coal flow" model. Part of the coal that arrives to Hebei from Shanxi is transferred from the port of Qinhuangdao which has been selected as the main port of the Bohai Bay. A portion of Liaoning province's coal demand is covered by Hebei, which also covers the demand of Tianjin province. Short sea shipping for the wider Bohai bay is, as mentioned above not significant accounting for 15% of the total sea transportation of coal but it is still important since we notice that Hebei and Shanghai are the two only nodes in the whole system. The slow percentage of transshipment is attributed to the high overall supply chain costs for the domestic coal to reach the coastal provinces of China. Even though it is an extreme example, the fact that the volume of coastal navigation is low, along with the proximity of the destinations to the origin, underline one of the reasons for the increased imports of coal.

<u>River mode</u>

Table 13 : Estimated river coal flows - base case scenario

Out / In	Jiangxi
Anhui	2.9
Shanghai	35.6
Total	**38.5**

Source: Author's calculations Unit: Million tons per year

Special attention should be given to Shanghai, since it is the only place in this application of the model that acts as a node for river provinces. Through Yangtze River, Shanghai exports the Russian coal to Jiangxi province after it covers its' own demand. This is characteristic of Yangtze river's importance on the coal flow of China, since we notice that inland navigation basically strengthens the proximity of coal sources outside the country and lowers the overall transportation costs.

Differences between the current situation and the base case scenarios

At this part of the analysis, it is important to underline the differences between the first two scenarios of the Coal Flow model application. This will give a better understanding of the changes on coal flows that are estimated to be undertaken, should the infrastructure upgrades take place.

Table 14: Current Vs. Base case scenario

Remarks	Current case (million Tons transported)	Base case (million Tons transported)	Change
↓ Short sea shipping	569.6	146.3	- 74.3%
↓ Rail mode	1721.8	969.5	- 43.7%
↑↑ Imports	172.9	903.8	+422.7 %

Source: Author's calculation

Constraint – remarks

A total of 3039 constraints were taken into account by the solver during the minimization of the objective function at this scenario of the model. As capacity was not an issue for the physically possible routes the ones that were considered as non- binding by AIMMS were those routes which were set with capacity zero as they were geographically impossible (e.g. Vostochny to Anhui since Anhui has no port).Those that were considered binding had a zero slack as their numbers were set very high (999999) in order to cater for the assumed infinite capacity. What is interesting however to note is the demand and supply flow constraints from the different nodes. Multiple demand and supply flow constraints were binding with shadow prices ranging from 15 to 100 tons. A change in those constraints would have a minimal impact on the objective function and would not affect significantly the optimal solution but implies that several different provinces can potentially acts as hubs for coal transportation.

5.2.4 Interpretation of Findings / Discussion of the base case scenario

Russian Dominance in the Chinese coal imports

Indonesia provides all of Guangdong's coal demand and Russia from Vostochny Port caters for the demand of Northeastern Jiangsu, Zhejiang and Fujian. Shaanxi and Shanxi provinces' production cover the demand gaps of the inland provinces.

The fact that Russia exports more than 300 million tons to the Chinese market is indicative of that county's potential of becoming the major coal provider of China, as it is demonstrated that it is the source of the most cost efficient routes. The main reasons for Russia's first place among the coal exporters to the Chinese market are summed up below:

- Proximity to the Chinese market. Russia's ports are less than half distance far from China than Indonesia and almost one fifth of the distance than Australia. It is therefore easy for someone to grasp the unfolded potential of Russian exports with Chinese destination in general.
- Infrastructure developments at the rail connections of the main Kuzbass basin connecting production to Vostochny port and Primorsky Krai region have set Russia capable to cope with the increased Chinese demand.
- Upgrading of the capacity of Vostcochny port. It has to be noted that the adoption in the model of Vostochny port as one of the two major Russian exporting ports in the Pacific region along with Vanino, was made as it is considered the most representative of the Russian market and is an all-year round an ice-free port. Vostochny port is also representative of future ports in the Primorsky Krai region. Due to the regions favorable position, the present research concludes that it is considered ideal for new coal terminal developments.

<u>Inner Mongolia and Xinjiang – paradox</u>

Shanxi and Shaanxi are the major suppliers of domestic coal with the first accounting for most of the supply due to its proximity to the northeastern coal demand centers. On the other hand Inner Mongolia and Xinjiang are completely out of the picture since they are relatively far from the demand centers. That result is troubling in a way, as it has been addressed in the 12^{th} FYP that the production centers of coal will be transferred to those areas. The part that follows will deal with that specific scenario in order to analyze the implications of the planned industry and production consolidation (12^{th} FYP).

<u>Australia losing to Russian and Indonesian exports</u>

The main coal trade partners of China based on proximity are Russia and Indonesia. Australia's role is not properly identified in this application of the model since among the main reasons that have placed Australia at the first position of coal exporters to China are:

a) The quality of Australian coal

b) The restricted capacity of Chinese railway system

c) The restricted capacity of Russian ports and railway

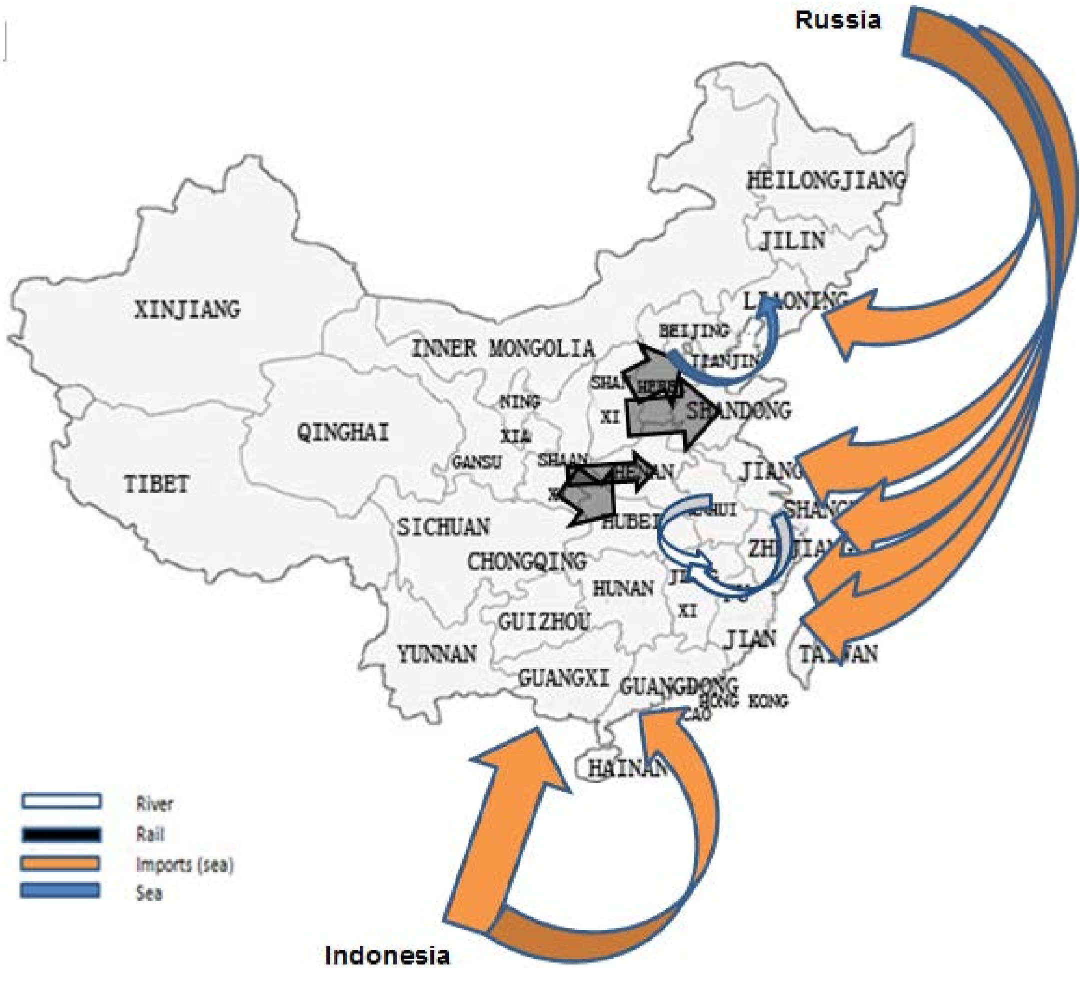
d) The low quality of Indonesian coal (low calorific value)

e) Competitive FOB prices of Australian coal.

All of the aforementioned parameters are not taken into account and therefore, by the single criteria of transportation cost Indonesia and mostly Russia play a protagonistic role at the coal flow network of China. It is important to note though that the increased production of coking coal in Indonesia and especially Russia allow this scenario to resemble the reality quite closely. That could otherwise be interpreted as an indication of the potential of Russia to become a major coal exporter for the Chinese market.

Finally and most importantly we notice that under the base case scenario, Russia exports an astonishing quantity of more than half billion tons per year. Keeping in mind that Russia has a current total capacity at its' Pacific ports of almost 100 million tons per year it is evident that significant capacity upgrades should take place if the country aims to become the major coal exporter to China.

Figure 11: Coal flows under base case scenario



Source: Author's estimations

5.3 Inner Mongolia and Xinjiang scenario

According to J.P, Morgan's estimation (2012) the increased coastal demand will result in a coal gap of approximately 200 million tons in 2020. That estimation in combination with the consolidation by the PRC Government of smaller regional mines and the transfer of the production centers to Xinjiang province and Inner Mongolia have led to the implementation of this particular scenario (12^{th} FYP).

5.3.1 Characteristics

The scenario accounts for all infrastructure upgrades both in Russia and China in addition to the following characteristics:

- Increased coastal demand: 5% per annum
- Decreased production at central provinces and increased production at Xinjiang and Inner Mongolia. The rates of yearly production decrease and increase until 2020 are 10%. In order to calculate the supply surplus of the producing areas an increase of 2% per year in south and south-western provinces' coal demand has been assumed.

5.3.2 Findings and analysis by mode

Major findings – discussion points of the Inner Mongolia & Xinjiang scenario

- Russia accounts for the 20% of the transported coal in China.
- Rail is the main mode of coal transportation, accounting for 67.7% of the coal transported.
- Xinjiang and Inner Mongolia cover 40% of the domestic demand.
- Lower utilization rates for the Bohai Bay and Tianjin Ports.
- Increased volume transported via the Yangtze River. (almost 100% comparing to the two previous scenarios

Sea mode

The total quantity of coal transported in 2020 reaches 3 billion tons. At the sea mode of coal flows under this scenario, we notice that Russia turns out to be the first coal exporter to China, with total exporting tonnage accounting for 70% of sea mode transportation and 20% of total coal transported in China.

Table 15: Estimated sea coal flows – Inner Mongolia & Xinjiang scenario

Out / In	Liaoning	Shandong	Shanghai	Zhejiang	Guangdong	Fujian	Total
Tianjin	25.0						**25.0**
Jiangsu		27.2					**27.2**
Hebei	45.9						**45.9**
Vostochny		67.8	58.5	143.6	87.2		**357.1**
Vanino	141.2				54.3	64.3	**259.8**
Australia					83.7		**83.7**
Indonesia					61.9		**61.9**
Total	**212.0**	**95.1**	**58.5**	**143.6**	**287.1**	**64.3**	**860.6**

Source: Author's calculation Unity: Million tons per year

Since the consolidation of domestic production has led the supply centers to the north – northwestern part of the country, Russian ports competitiveness is intensified. Its' proximity to the China market allows Russia to become the leading coal exporter to China, provided however that the sole criteria is transportation costs. Australia and Indonesia continue to service the northern coasts of China but with much lower volumes, and accounting for roughly 18% of sea transportation and just 5% of the total quantity transported.

Rail mode

Rail still remains the main mode of coal transportation in China, accounting for 67.7% of the all the transported volume. Inner Mongolia and Xinjiang provinces cover almost 40% of domestic demand via rail while short sea shipping cannot compete with the lower costs of Russia that ships coal without intermediate-transshipment handling fees and lower overall costs. Tianjin and Bohai bay ports have lower utilization rates with unutilized excess capacity.

Table 16: Estimated rail mode coal flows – Inner Mongolia & Xinjiang scenario

Out/In	Shandong	Jilin	Heilongjiang	Henan	Hubei	Jiangsu	Total
Liaoning		47.5	48.4				**95.8**
Shaanxi				57.8	29.2		**87.1**
Gansu						283.8	**283.8**
Shanxi	54.7						**54.7**
Neimeng	67.1						**67.1**
Xinjiang					114.5		**114.5**
Total	**121.7**	**47.5**	**48.4**	**57.8**	**143.7**	**283.8**	

Out/In	Gansu	Sichuan	Guangxi	Tianjin	Beijing	Hebei	Total
Yunnan			5.3				**5.3**
Neimeng				286.3	17.8	304.6	**608.6**
Xinjiang	300.6	90.2					**390.8**
Total	**300.6**	**90.2**	**5.3**	**286.3**	**17.8**	**304.6**	**1707.6**

Source: Author's calculation Unity: Million tons per year

River mode

Part of the coal that originates from Xinjiang and arrives at Chongdu in Sichuan province is transferred via the Yangtze River to cover Jiangxi and Hunan provinces' coal demand.

Table 17: Estimated river mode coal flows– Inner Mongolia & Xinjiang scenario

Out / In	Jiangxi	Hunan	Total
Anhui	2.9		**2.9**
Sichuan	35.6	30.5	**66.1**
Total	**38.5**	**30.5**	**69.0**

Source: Author's calculation Unity: Million tons per year

5.4 Sensitivity analysis

The sensitivity analysis at this part of the research has two different goals and model applications. Firstly we will assess the importance of certain infrastructure developments in China by estimating the coal flows, assuming that no imports are possible. Secondly a closer look will be given at rail infrastructure of China in order to estimate the coal flows should the announced upgrades not take place. In both the aforementioned scenarios the importance of Yangtze River is underlined.

5.4.1 No constraints – no imports scenario

Characteristics

In order to see how the trade flows of coal will change if we all the infrastructure developments take place in Russia and in China and fully estimate the capacity restrain problem that the Chinese coal logistics network faces the same model created will be applied with relaxed restrictions and no imports available. The assumptions taken are as follows:

- All the capacity requirements are met due to adequate infrastructure development.
- The domestic supply is assumed to be sufficient to cover the demand of China due to the increased productivity of Inner Mongolia and so no imports are allowed.

Findings and analysis by mode

With no constraints on capacity and the option of imports not available this version of the model aims to identify the lowest cost transportation corridors of coal in China and predict the most cost-efficient routes based on an energy policy of self-sustainable resource management. Almost 69% of flows are completed via rail and 28% via short-sea shipping while just 0.02% of the coal flows use the Yangtze river transportation corridors.

Rail mode

From the rail mode we have to distinguish Shaanxi, Shanxi and Neimeng provinces as the major coal suppliers. Shaanxi provides coal to Gansu, Henan, Sichuan and Hubei. Hubei via river sends coal imported by Shaanxi to Jiangxi which gets also coal via river from Anhui. We notice that Shaanxi supplies mainly the central and western provinces. This fact underlines the importance of Xi'an, as a city that almost 20% of rail coal flows pass through.

Table 18: Estimated rail mode main coal flows – no constraints/no imports scenario

Out / In	Shandong	Beijing	Henan	Hubei	Gansu
Shaanxi			57.8	215.3	4.7
Guizhou					
Yunnan					
Shanxi	225.7				
Inner Mongolia		17.8			
Total	**225.7**	**17.8**	**57.8**	**215.3**	**4.7**
Out / In	**Sichuan**	**Guangxi**	**Tianjin**	**Hebei**	**Total**
Shaanxi	24.0				**301.8**
Guizhou		45.4			**45.4**
Yunnan		5.3			**5.3**
Shanxi				342.2	**567.8**
Inner Mongolia			620.4		**638.2**
Total	**24.0**	**50.7**	**620.4**	**342.2**	**1558.5**

Source: Author's calculations Unit: Million tons per year

Sea mode

Shanxi and Inner Mongolia send coal to Tianjin and Hebei. The latter two regions act as the main transportation nodes of coal, explaining the evolvement of the Bohai Bay's importance for the domestic coal flows. From coal that goes through Tianjin the south-eastern coastal provinces of Jiangsu, Zhejiang, Fujian, Guangdong and Guangxi are served. Hebei acts as the intermediate node for Shanxi's coal to reach Guangdong.

Table 19: Estimated sea mode coal flows – no constraint/no imports scenario

Out/In	Jiangsu	Shanghai	Zhejiang	Fujian	Guangdong	Guangxi	Total
Tianjin	256.6	58.5	143.6	64.3	30.0	14.4	**567.4**
Hebei					146.3		**146.3**
Total	**256.6**	**58.5**	**143.6**	**64.3**	**176.3**	**14.4**	**713.7**

Source: Author's calculations Unit: Million tons per year

River mode

Shaanxi also acts as the major supplier of coal for provinces that have Yangtze River ports. Jiangxi and Hunan are the sole provinces that import coal through the Yangtze River, with imports from Shaanxi through Hubei and from Anhui's production.

Table 20: Estimated river mode coal flow – no constraints/no imports scenario

Out / In	Jiangxi	Hunan	Total
Anhui	2.9		**2.9**
Hubei	35.6	30.5	**66.1**
Total	**38.5**	**30.5**	**69.0**

Source: Author's calculations Unit: Million tons per year

5.4.2 Da-Qin and additional railway constraints - scenario

Characteristics

Similar to Mou and Li's approach (2012) the Da-Qin railway capacity was also included in an earlier application of the model in order to estimate the shifts and differences at the major coal flows. However at this application, in order to fully estimate the impact of restricted railway capacity in China, imports are not allowed and Shaanxi – Hebei railways' capacity restriction is also incorporated.

Findings and analysis by mode

Rail mode

Comparing to the results of the first model application above we notice an increase in the coal flows from Shanxi and Inner Mongolia towards Shandong port at Jinan province. Comparing with the base case scenario there is a significant increase of the rail mode usage which is attributed but not at the levels of the previous scenario. That is attributed to the fact that capacity constraints make it less profitable to use transportation hubs. Thus, an otherwise profitable option to transfer coal through a hub-province is less frequently met at this scenario. The Da-Qin capacity constraint has minimized the coal volumes transported from Tianjin while the capacity constraint at the railway line between Shaanxi and Hebei provinces has ,minimized the short-sea shipping activities originated from ports in the region of Bohai Bay. Comparing though to the base case scenario those are high since imports are not allowed.

Table 21: Estimated rail mode flows – Da-Qin & additional railway constraints

Out / In	**Henan**	**Hubei**	**Gansu**	**Sichuan**	
Shaanxi	51.1	215.3	11.4	24.0	
Shanxi	6.7				
Total	**57.8**	**215.3**	**11.4**	**24.0**	
Out/In	**Shandong**	**Hebei**	**Tianjin**	**Beijing**	**Total**
Shaanxi					**301.8**
Shanxi	461.1	100.0			**567.8**
Inner Mongolia	50.9		358.9	57.9	**467.7**
Total	**512.0**	**100.0**	**358.9**	**57.9**	**1337.3**

Source: Author's calculations Unit: Million tons per year

Sea mode

We notice that Bohai Bay ports (Tianjin) and Shandong are vital for the domestic sea coal flows. Their throughput though varies, depending on the volume of imports of coal since there is significant difference from the base case scenario on the volumes transported.

Table 22: Estimated sea mode flows – Da-Qin & additional railway constraints

Out / In	**Shanghai**	**Zhejiang**	**Fujian**	**Guangdong**	**Guangxi**	**Jiangsu**	**Total**
TianJin	58.5	114.7	64.3	176.3	14.4		**428.3**
Shandong					28.9	256.6	**285.4**
Total	**58.5**	**114.7**	**64.3**	**176.3**	**43.2**	**256.6**	**713.7**

Source: Author's calculations Unit: Million tons per year

River mode

It is also important to underline the increased importance of Yangtze River for the coal supply of Jiangxi and Hunan Provinces. Increased transport costs still make it less profitable to import coal from Xinjiang Province while short sea shipping and rail still account for approximately 28% and 70% of the domestic trade.

Table 23: Estimated river mode coal flows – Da-Qin & additional railway constraints

Out / In	**Jiangxi**	**Hunan**	**Total**
Anhui	2.9		**2.9**
Hubei	35.6	30.5	**66.1**
Total	**38.5**	**30.5**	**69.0**

Source: Author's calculations Unit: Million tons per year

Major Findings

SRQ 1 :

- As capacity upgrades are taken into consideration in the application of the model (5.2 No constraints model) we notice that an increase of the imported quantities takes place. That is attributed to the fact that capacity upgrades take place both in China and Russia.
- Central provinces act as main transportation nodes due to their rail connectivity and in the cases of Anhui, Sichuan, Shanghai due to their access to Yangtze River.
- As capacity upgrades take place and industry consolidation pushes the production centers to the North and Northwestern parts of China (5.3 Inner Mongolia and Xinjiang scenario) Yangtze river plays an increasingly important role for coal transportation

SRQ 2:

- Capacity upgrades at the Russian coal transportation network will enable Russia to become the number one coal exporter to China (5.2 & 5.3 scenarios).
- Primorsky Krai (south-eastern) region of Russia is according to this research ideal for infrastructure developments and building of new coal terminals destined for exporting to China due to its proximity to the market.

SRQ 3:

- Given the capacity upgrades, the single most decisive variable for the choice of origin of coal is transportation cost.
- A consolidation of the Chinese production (5.3 scenario) would lead to increased rail transportation and transformation of certain provinces to transportation hubs.
- The role of the Bohai Bay ports is inversely changeable based on the cost of coal from other countries. However at a worst case scenario for those ports (5.2 No constraints model) they still account for 15% of the sea coal flows of China; an indication of their importance and resilience to the changing economic environment.
- River flows are present at each scenario application as they provide a much cheaper alternative than rail transportation. The fact that they account for such a small part of the total coal transportation is attributed to physical barriers e.g. no river ports at major producing or consuming provinces.

SRQ 4:

- Russia dominates the coal exports to China with Australia coming second and Indonesia third (Scenario 5.3 / Table 13).
- Rail accounts for 67.7% of the transported volume.
- Bohai Bay ports have excess capacity as it is more profitable to import coal straight to the destination or transfer it via rail.
- Yangtze River' s becomes vital for the supply of Hunan and Jiangxi provinces and Shanghai acts as a hub between sea and river coal flows.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions and infrastructure policy recommendations

The results drawn by the analysis of the different scenarios at the previous chapter, as well as the literature view and the sector analysis have led to the conclusion that infrastructure developments in Russia and China will increase the volume of transported coal between the two countries and within China. Russia has potential to ascend to the first position among the coal providers of China but this is something that depends not only on infrastructure upgrades but also on resource criteria, socioeconomic factors and competition. The assumptions taken during the research have limited the applicability of the results to a ceteris paribus situation, but nevertheless certain clear conclusions were surfaced that allow us to make the following policy recommendations.

First, the emergence of Yangtze River as an important route for the transportation of coal was clearly identified. The increasing volumes of coal transported through inland China due to the increasing demand and the consolidation of production will have a more cost-efficient passage through Yangtze River. The low capacity of the river ports and the physical boundaries that do not allow the river to reach at the major coal importing and exporting provinces limit its' potential. Possibly some capacity upgrades along with the increasing of the river's connectivity via rail to provinces that have no access to it, would result in lower transportation costs and lower pressure on the existing rail infrastructure. On that perspective, Shanghai's role would be intensified as a hub for imported coal or coal transferred via short-sea shipping from the northern part of the country.

Second, the Da-Qin railway's vital role in transporting coal originated from Inner Mongolia to the north-eastern coastal provinces of China is underlined at the basic application of the constructed model as well as at the sensitivity analysis' scenario that was conducted. Given that the 12th FYP of PRC calls for gradual movement of the coal production centers to Inner Mongolia and Xinjiang, it is advised that priority should be given at the capacity upgrades of this railway line.

Third and last for the part of China, Bohai Bay ports' future role should be carefully assessed. It has been indicated that at levels of increased imports and sufficient railway capacity Bohai Bay might account for as low as 15% of the sea coal flows of China. That, however is a highly unlikely scenario from many aspects since rail infrastructure upgrades are far from completed and imports will not reach the high levels of the scenarios run before domestic production also increases. Thus it should be kept in mind, that the future role of the ports located at the Bohai Bay in the northern part of China, is highly dependable on the volumes of produced and imported coal. A higher dependence on imports of coal could lead to a decreasing role of the northern coal terminals.

Fourth, the potential of Russian coal exports seems to be substantial comparing to the rest two major coal importers to China. Given the capacity upgrades in the railway connectivity and the capacity upgrades in the port sector of the Pacific side of Russia, the country has potential to become the most important coal supplier of China. Possibly, the ports at the south-eastern part of China should cater for the increased imports in the future by investing on capacity upgrades or even increasing their connectivity to inland provinces. Given a potential shift of the role of China towards a coal exporting status, those ports could act also as getaways for the Pacific Market (Japan).

Lastly, the region of Primorsky Krai in Russia has been identified as the most suitable for infrastructure developments. Due to its' favorable position close to China and the all-year ice-free status, this region should be the center of most of the future port developments from the Pacific side of Russia if it aims to increase access to the Pacific.

6.2 Research recommendations

- Socioeconomic impact

The scope of this research has been mainly on the transportation of coal and the infrastructure developments that will increase cost savings. We identified the most cost-efficient routes on several scenarios and indicated certain key regions and parameters that would potentially lead to the increase of Russian coal exports to China and from the northern part of China to its' coastal regions. The constructed model was used in order to calculate future coal flows. The results were examined from a transportation and cost-efficiency perspective. However, the "coal-flow" model could also be the starting point for research on the future socioeconomic impact of infrastructure developments and could have a broader application to other commodities as well.

- Environmental aspect

Several researches have been made on multimodal transportation in China as it was addressed in the literature review. The bottlenecks created on the railway system of the country have a major economic impact and also affect the trade flows. However, there have not been many researches from an environmental perspective. At the coal market specifically the environmental impact is substantial, not only at the production but at the transportation side as well. Pollutants such as CO2 and

Sulphur oxide that originate from the high use of trucks, train and short sea shipping should be controlled and policy measures should be taken in order to prevent further environmental deterioration in China. From a policy perspective, the Chinese Governments' will to curve pollution at the most densely populated areas of the country has been evident in the12th FYP. A future policy that would lead to different fuel usage in the sea limits of China much resembling the SECAs in Europe and USA could have major economic impact on the shipping industry implicated. Therefore the need for researches that would assess the environmental aspect of coal transportation and would take into consideration various future policy scenarios is bigger and more important than ever.

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Appendices

Table 24: Sea Port to Port Unit Transportation Costs (0.04 RMB /Ton / Km)
Unit : RMB / ton

	Liaoning	Hebei	Tianjin	Shandong	Jiansu	Shanghai	Zhejiang	Fujian	Guangdong	Guangxi
Liaoning	0	12.44	16.16	20.16	25.12	39.84	42.8	64.36	98.6	121.2
Hebei	12.44	0	9.4	27.92	32.88	47.64	50.6	72.16	106.36	128.96
Tianjin	16.16	9.4	0	31.64	36.6	51.4	54.32	75.92	110.16	132.68
Shandong	20.16	27.92	31.64	0	7.2	29.2	32.08	53.8	88	110.6
Jiansu	25.12	32.88	36.6	7.2	0	28.44	31.32	53.04	87.28	109.88
Shanghai	39.84	47.64	51.4	29.2	28.44	0	9.04	31.04	65.28	87.84
Zhejiang	42.8	50.6	54.32	32.08	31.32	9.04	0	25.56	59.8	82.36
Fujian	64.36	72.16	75.92	53.8	53.04	31.04	25.56	0	39.4	62.16
Guangdong	98.6	106.36	110.16	88	87.28	65.28	59.8	39.4	0	31.56
Guangxi	121.2	128.96	132.68	110.6	109.88	87.84	82.36	62.16	31.56	0

Source: Author’s estimations

Table 25: River Port to Unit Port Transport. Costs (0.04 RMB/ton/km)
Unit : RMB / ton

	Chongqing (Sichuan)	Yueyang(Hunan)	Hankou(Hubei)	Jiujuang(Jiangxi)	Wuhu(Anhui)	Shanghai(Shanghai)
Chongqing (Sichuan)	0	42.16	58.52	44.76	74.68	95.96
Yueyang(Hunan)	42.16	0	9.36	21.28	34.24	55
Hankou(Hubei)	58.52	9.36	0	9.96	27.2	45.96
Jiujuang(Jiangxi)	44.76	21.28	9.96	0	16.6	33.6
Wuhu(Anhui)	74.68	34.24	27.2	16.6	0	19.52
Shanghai(Shanghai)	95.96	55	45.96	33.6	19.52	0

Source: Author’s estimations

Table 26: Rail Unit Transport Costs (0.12 RMB/t/km) Unit :RMB/ton

	Beijing	Tianjin	Liaoning	Jilin	Heilongjiang	Shandong	Anhui	Jiangsu	Shanghai	Zhejiang	Jiangxi	Fujian	Hebei
Beijing													
Tianjin	16.44												
Liaoning	88.92	84.84											
Jilin	125.52	121.44	36.6										
Heilongjiang	154.56	162.48	65.64	29									
Shandong	59.64	43.2	128.04	165	193.68								
Anhui	128.88	116.76	201.6	238	267.24	73.56							
Jiangsu	139.2	122.76	207.6	244	273.24	79.56	37.44						
Shanghai	175.56	159.12	243.96	280	309.24	115.92	73.8	36.36					
Zhejiang	190.68	174.24	259.08	296	324.72	131.04	54.12	51.48	24.12				
Jiangxi	173.88	173.28	258.12	295	322.68	136.44	57.36	100.56	100.44	76.32			
Fujian	280.08	263.64	348.48	385	414.12	220.44	143.5	140.88	140.76	116.64	74.64		
Hebei	33.24	50.28	135.12	172	200.76	36.12	109.7	115.68	152.04	167.16	155.16	229.8	
He'nan	82.68	99.72	184.56	221	250.2	79.92	77.4	83.4	119.76	134.88	111.24	185.9	49.44
Hubei	147	164.04	236.64	273	302.28	144.24	141.7	147.72	147.6	123.48	46.92	121.6	113.8
Hu'nan	189.96	207	279.6	316	345.24	187.2	146.6	144	143.88	119.76	50.16	118.1	156.7
Guangdong	274.68	291.72	364.32	401	351.36	258.12	219.1	216.48	216.36	192.24	122.64	190.6	241.4
Guangxi	307.32	324.36	409.32	758	462.6	304.56	251.8	249.12	249	224.88	155.28	223.2	273.8
Shaanxi	139.08	156.12	228.72	265	294.36	141.24	138.7	144.72	181.08	196.2	169.44	286.7	110.8
Gansu	217.32	233.76	306.24	355	371.88	222.36	219.8	141.84	262.2	277.32	250.56	367.8	191.9
Qinghai	251.04	268.2	340.68	377	406.32	248.28	245.8	251.76	288.12	303.24	276.48	393.7	217.8
Xinjiang	452.16	469.32	541.8	578	607.44	449.4	446.9	452.88	489.24	487.8	526.92	594.8	418.9
Sichuan	245.04	262.2	334.68	371	400.32	242.28	239.8	245.76	282.12	306.24	268.68	336.6	211.8
Guizhou	304.68	321.72	394.32	431	459.96	301.92	249.1	246.48	246.36	222.24	152.64	220.6	271.4
Yunan	381.36	398.4	471	508	536.64	374.28	371.8	323.16	368.28	344.16	229.32	297.2	348.1
Shanxi	61.68	78	150.6	187	216.24	63.84	137.4	143.4	179.76	194.88	233.28	302.5	27.72
Neimeng	80.04	96.48	168.96	206	234.6	139.68	213.2	219.24	255.6	270.72	320.88	396.4	104.5
Ninngxia	161.16	177.6	250.08	287	315.72	220.8	240.2	246.24	282.6	297.72	270.96	388.2	185.6

	He'nan	Hubei	Hu'nan	Guangdong	Guangxi	Shaanxi	Gansu	Qinghai	Xinjiang	Sichuan	Guizhou	Yunan	Shanxi	Neimeng
Hubei	64.32													
Hu'nan	107.28	42.96												
Guangdong	192	127.68	84.72											
Guangxi	224.4	160.32	117.36	160.08										
Shaanxi	61.32	125.64	168.6	253.32	285.96									
Gansu	142.44	206.76	249.72	334.44	367.08	81.12								
Qinghai	168.36	232.68	275.64	360.36	393	107.04	25.92							
Xinjiang	369.48	433.8	476.76	561.48	594.12	308.16	227	252.96						
Sichuan	162.36	208.44	230.76	303.24	219.84	101.04	140.6	166.56	363.12					
Guizhou	222	157.68	114.72	187.2	103.8	217.08	256.7	282.6	479.16	116.04				
Yunan	298.68	234.36	191.4	263.88	180.48	233.04	272.6	298.56	495.12	132	76.68			
Shanxi	69.24	141.48	184.44	269.16	301.8	78.12	159.2	185.16	386.28	179.16	295.2	311.16		
Neimeng	163.44	227.76	270.72	355.44	388.08	154.92	137.3	163.2	364.32	255.96	372	387.96	76.8	
Ninngxia	162.84	227.16	270.12	354.84	387.48	101.52	56.16	82.08	240.96	161.04	277.08	293.04	157.92	81.12

Source: Author’s estimations, MOR, Mou & Li (2012)

Table 27: Coal Gaps of China's Provinces

Province	Coal Gap (Supply- Demand)	Province	Coal Gap (Supply- Demand)
Beijing	-18	**Shandong**	-226
Tianjin	-53	**Henan**	-58
Hebei	-196	**Hhubei**	-149
Shanxi	57	**Hunan**	-31
Neimeng	676	**Guangdong**	-176
Liaoning	-116	**Guangxi**	-65
Jilin	-47	**Hainan**	-9
Heilongjiang	-48	**Chongqing**	-32
Shanghai	-57	**Sichuan**	-24
Jiangsu	-257	**Guizhou**	45
Zhejiang	-144	**Yunan**	5
Anhui	3	**Shaanxi**	302
Fujian	-64	**Gansu**	-17
Jiangxi	-39	**Qinghai**	7
Xingjiang	33	**Ningxia**	5

Source: CESY 2012 Unit: Million tons